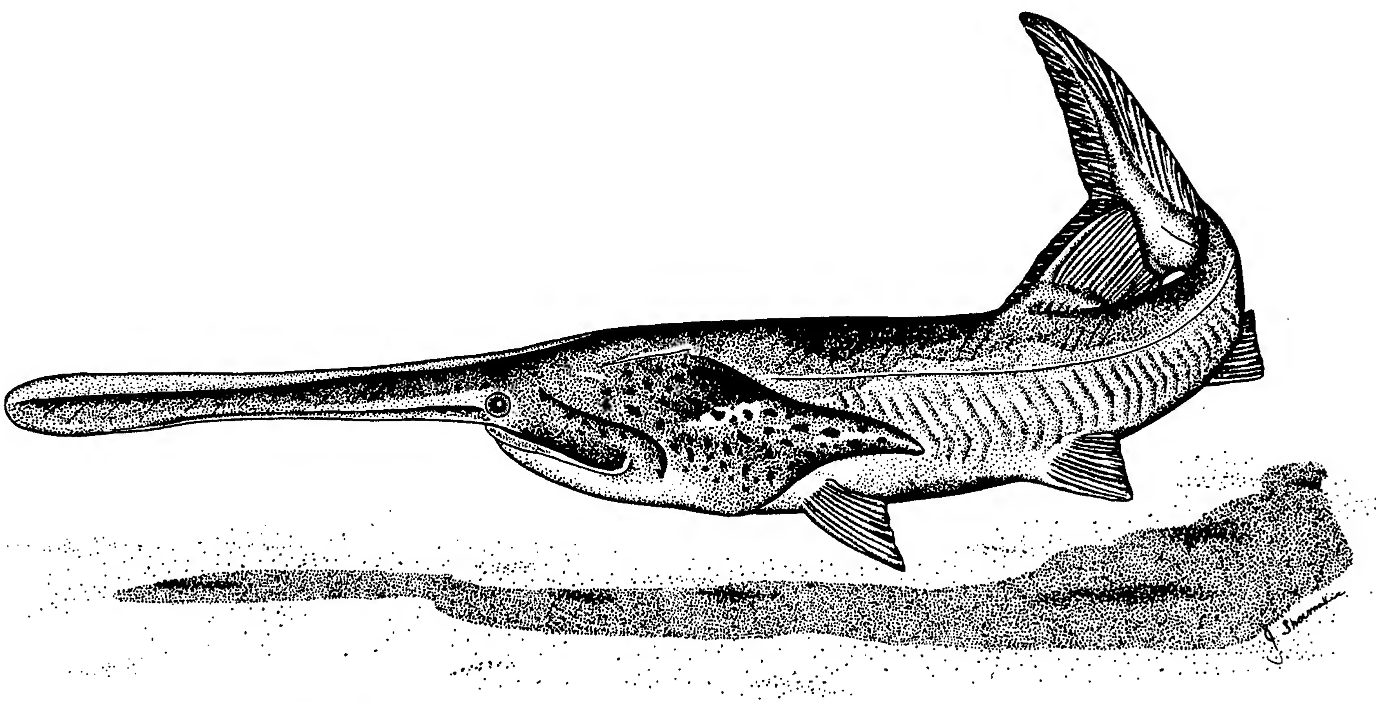
Biological Report 19
October 1993

Proceedings of the Symposium on

Restoration Planning for the Rivers of the Mississippi River Ecosystem



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Restoration Planning for the Rivers of the Mississippi River Ecosystem

Edited by

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Preface

I have often wondered why, at times, I feel such a sense of outrage and despair even after just returning from meetings where we were engaged in planning the first mitigation project for the Missouri River, or were informed that someone in Congress or the Corps of Engineers has an interest in studying the prospect of restoring sediment movement through a large storage reservoir on the river, or were told that we might receive the necessary permits to put a few large trees and some organic matter back into the Missouri's channels. Don't these projects reflect successful restoration efforts?

My state of mind was best explained by Reisner (1991): "Conservationists tend to feel like born losers, even if things are going their way." Perhaps this statement is true because there is such an overwhelming sense of historic, ongoing, and unstoppable loss that is evident every day for those of us who work with native ecosystems.

Schmulbach (1988) noted that humans start life with an innate fascination with nature, but our culture slowly applies a set of accepted values until only a few of us remain naturalists, while most come to view nature as only a resource to be used. Naturalists believe that humans cannot live apart from other organisms with which they co-evolved. The worth of an organism is found in its contribution to our understanding of life and not in man's ability to convert it into food, fiber, money, or prestige (Janovy 1985).

Examples abound of the mismanagement of biota in the Mississippi River ecosystem. Mussels were so numerous at one time in the upper Mississippi and its tributaries that a single bed at New Boston, Illinois, yielded 10,000 metric tons of shells in 3 years, representing a hundred million mussels (Madson 1985). By 1920, 60,000 metric tons of shells were taken yearly in the United States. Dam construction began to bury the remaining mussel beds by the 1930's, and water pollution killed many more. By the 1940's "shelling" was a thing of the past (Madson 1985).

In 1908, the Illinois River produced 10% of the total catch of commercial freshwater fish in the United States; the annual yield was 10.9 million kg (198 kg/ha). Intensified floodplain agriculture and pollution reduced the yield to 43 kg/ha by the 1950's, and to less than 5 kg/ha by the 1970's (Sparks 1992).

For hundreds of thousands of years melting western snows and Great Plains' rain storms were aggressively moving the Rocky Mountains to the Gulf of Mexico via the Missouri, Arkansas, Red, and other rivers. In the spring of 1543 DeSoto reported that Indians were living in trees in Louisiana, fishing for gar with drowned animals for bait (Reisner 1991). The lower Mississippi River was in full spring flood and 100 km wide.

The "flaked-off skin of a continent," Reisner (1991) reminds us, is the reason there is a southern Louisiana. Dams, levees, and channelization projects have effectively halted the ancient process of sediment transport. There were 2.5 million ha of coastal wetlands in Louisiana 137 years ago. By 1913, Louisiana was losing 18 km^2 of wetland annually; by 1946 that figure was 41 km^2, and today it is more than 130. A reduction in the available sediment supply for delta construction has meant saltwater intrusion inland from the Gulf of Mexico (Reisner 1991). Southern Louisiana was the winter home for 100 million migratory waterfowl, and 80% of the marine life of the Gulf of Mexico depended on the Mississippi River delta wetlands. Those wetlands are being destroyed, along with upstream river systems throughout the basin.

The 4.8-million-km^2 Mississippi River basin drains 31 states and includes more than 90 major river systems. The combined loss of fish and wildlife in this basin from water development projects and pollution probably exceeds the slaughter of billions of passenger pigeons and 60 million bison (Reisner 1991) as an environmental catastrophe.

This symposium was organized to review the status of fish and wildlife resources of the Mississippi River ecosystem. The objectives were as follows:

1. to present some of the existing information on native and introduced fish, methods for surveying the aquatic communities, human impacts, effects of changes in the geomorphology and hydrology on the biota, and values associated with riverine resources throughout the basin;
2. to identify existing or planned actions that might be useful for fisheries management in rivers within the basin; and
3. to identify minimal requirements for the restoration of important finfish and shellfish stocks, other aquatic resources, and entire ecosystems.

Authors were encouraged to relate their segment of river system to tributaries and to the river downstream. The impacts of altered hydrologic, sediment, and organic matter cycles were to be described, as well as such changes as the availability of woody debris in the river cross-section, loss of floodplain and side-arm connection, and changing water quality. The symposium was held at the 122nd annual meeting of the American Fisheries Society on 13-15 September 1992 in Rapid City, South Dakota.

The published proceedings includes papers covering 19 different large river systems in the Mississippi River basin and broad perspectives on sediment transport, riparian plant communities, altered hydrologic cycles, contaminants, threatened and endangered species, and communication. Several additional papers were prepared for oral presentation that were not included in the proceedings because of the busy schedules of the authors. The following is a listing of these oral presentations.

White River: A Case History. By Kenneth E. Shirley, Arkansas Game and Fish Commission, Little Rock, AR 72205.

One Hundred Years of Change in the Illinois. By Richard E. Sparks, Illinois Natural History Survey, Havana, IL 62644.

The Atchafalaya River Basin: A Case Study in Southern River Swamp Systems. By C. Frederick Bryan, U.S. Fish and Wildlife Service, Louisiana Cooperative Fish and Wildlife Research Unit, 124 School of Forestry, Wildlife, and Fisheries, Louisiana State University, Baton Rouge, LA 70803.

Ohio River: Fishes, Mussels, and Environment. By William D. Pearson, B. Juanelle Pearson, Jerry G. Schulte, and Andrew C. Miller, Water Resources Laboratory, University of Louisville, Louisville, KY 40292.

The Wisconsin River. By Bob Martini, Wisconsin Department of Natural Resources, Rhinelander, WI 54501.

The Clinch River System: A Biologically Unique River System of the Southeastern Mississippi River Basin. By Christopher J. O'Bara, Richard J. Neves, and Paul L. Angermeier, Center for the Management Utilization and Protection of Water Resources, Tennessee Technological University, Cokeville, TN 38505.

The Platte River Basin and its Fisheries: Past Changes, Present Condition and Future Outlook. By J. Larry Hutchinson and Edward J. Peters, Nebraska Game and Parks Commission, 2200 North 33rd, Lincoln, NE 68508.

Back from Beyond the Brink: The Kanawha River Chronicle. By Donald C. Hershfeld, Michael Hoeft, and George Kincaid, Huntington District, U.S. Army Corps of Engineers, 502 Eighth St., Huntington, WV 25701.

Use and Misuse of Artificial Propagation on the Recovery of Fish Populations. By Fred W. Allendorf, Division of Biological Sciences, University of Montana, Missoula, MT 59812.

We must view preservation and restoration of various segments of the Mississippi River ecosystem for more profound reasons than for increasing the catch of commercial and sport fish species. This system is a natural resource heritage. On a long-term basis, restoration offers the only option capable of preserving a desirable quality of life. Schmulbach (1988) said it well: "although we attempt to escape the restrictions of the natural world, man can only live so long on capital. The planet's natural resources are limited, as is their capacity to endure and even if the human majority fails to appreciate the intrinsic value of many species, it is in the vested interest of humans that all species and ecosystems survive."

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Contents

Introduction to the Symposium "Restoration Planning for the Rivers of the Mississippi River Ecosystem" and to MICRA

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We wish that the record were better concerning how rivers have fared in the face of water resource developments and that the future were brighter; however, progress has been made. Fisheries scientists and managers are developing new partnerships and are more assertive in their respective roles. Aquatic resources in North America are not in very good shape when one views the condition of water quality, riparian habitat, and fisheries, which will be discussed during the symposium. Riparian habitats are among the world's richest ecosystems. In fact, one might say that the quality of human life is revealed by the condition of rivers and streams, and as such they have become an important litmus test for the quality of life. The life blood of these aquatic and riparian ecosystems is the water that flows through them. Also, this liquid, with its load of nutrients, exits the watershed and becomes the life blood for estuaries and the breeding and nursery habitats critical for many marine fisheries.

River ecosystems are exceedingly complex, and people have managed to "mess them up." Although, North American rivers are generally in better condition than those in Europe and the former Soviet Union, there is no pride to be found in our treatment of rivers. However, there are great river systems in the world that are not yet "broken," but plans are underway to change them as this conference meets. Our neighbors in the South American countries of Brazil, Paraguay, Argentina, Uruguay, and Bolivia share the 3,200-km river system of the Parana and Paraguay rivers, which flow from the "empty lands" of Bolivia and Brazil, through Paraguay and Argentina, and empty into the South Atlantic Ocean between Uruguay and Argentina. To make these waters navigable all months of the year, these five countries are planning to dredge, levee, and build ports along the system. Planners expect that these changes will transform this great river system into a year-round commercial waterway that will rival the development on the Mississippi River system. The governments of these five South American countries intend that large tracts of undeveloped land in northern Paraguay and south-central Brazil be opened to farming and commerce by transforming their rivers into commercial waterways. We must share our experiences with them.

Generally, we have used our rivers in North America for just about everything one could think to haul up, float down, pump out, and dump in. Our coastal waters receive billions of cubic meters of municipal effluent and millions of cubic meters of industrial wastewater each year. The quality of most of this water does not meet current water standards for use by humans and wildlife.

Riparian habitats were never plentiful in North America. In the 48 contiguous states of the United

States, only 6% of the land mass supported riparian vegetation, and we have already lost two-thirds of these lands. We can expect remaining riparian habitat to continue to diminish if the loss of stream habitat isn't stopped.

The dialogue of this symposium centers on the Mississippi River drainage, one of the world's great river systems. This system drains about 12% of the area of North America and is the most significant environmental factor influencing the Gulf of Mexico. Fisheries managers in the 28 states in the Mississippi drainage have identified more than 90 tributaries and 80 species of fish of great concern. Fisheries scientists and managers participating in this symposium will discuss nearly a third of these 90 tributaries. These researchers are intimately familiar with their river system's habitat, water quality, flora, and fauna and with the relationships between the components of these ecosystems. They are the best hope to guide restoration of lost fish and wildlife values. These same researchers will readily admit the limitations available data dictate; however, they will also point out that sufficient information is available to stop the loss today and to begin a process of restoration. Recommending more research in lieu of action is, in our opinion, unconscionable.

Governments do not set out to destroy riverine values, and water development projects have provided such benefits as flood control, navigation, irrigation, and power production. But in the development process, the ecosystems have been damaged, and values have been lost. Rivers suffer from the cumulative effects of thousands of small, and some not so small, abuses. It is essential to adopt an approach that balances habitat conservation with water resources development.

Much of the problem with the way we have treated rivers has to do with the way our institutions and governments are organized. If one wished to condemn rivers to a long, slow, and sure death, the present governmental process was seemingly designed to achieve that end. North America is shared by three countries. Much of the border between the United States and Mexico is defined by a line drawn down the center of the Rio Grande River. To the north, much of the border between the United States and Canada is defined by a line dividing the Great Lakes and the St. Lawrence River. Farther to the north and west along the border between Alaska and British Columbia, most rivers beginning in Canada's interior run through southeastern Alaska and empty into the Pacific Ocean.

If governments were able to exert complete control over fish, as they can over their citizens, one could imagine that Mexican fish would be confined to the south side of the Rio Grande River and U.S. fish to the north side. Salmon migrating out of Canada would be required to carry passports and to clear U.S. customs to reach the ocean pastures to grow. These same salmon would be required to clear Canadian customs when returning to their natal streams to spawn. Unfortunately, fish and environmental problems show little regard for the boundaries that define our territories.

Selecting the middle of adjoining rivers as the boundary between countries and states has made management of these systems difficult. Mid-river state boundaries are especially common in the Mississippi River watershed. Consequently, 28 states, the Federal Government, and numerous Indian tribes share responsibility for management of the resources in the Mississippi River basin. In addition, the Federal Government has divided the responsibility for fisheries, water, and habitat between 37 agencies within 9 executive-level departments. It would be difficult to design a more complicated management system for river resources. But even worse, the Federal Government, as well as many of the states, is organized by constituent group (recreational, commercial, aquaculture) and salinity (freshwater vs. marine). Most of our coastal states have separate management agencies for sport and commercial fisheries. The fish do not realize this of course, and essential decision making with regard to water quality and habitat maintenance has become bogged down as states engage in "turf battles." Governments also squabble over states rights versus federal rights versus tribal rights, while the health of rivers has been lost.

The range, difficulty, and complexity of challenges that confront managers of the multiple jurisdictions affecting a river system are staggering. But if we can put differences and squabbling aside and overcome the multiple-jurisdiction problems to build systemwide approaches to navigation and electrical power, why can't we develop systemwide approaches that include fish and wildlife? The rule-making process created these circumstances, and it is the rule-making process that can lead to change; however, priorities will have to change.

Ultimately, much of the responsibility for changing the rules rests with our elected representatives. But responsibility for change also rests in part with fisheries scientists and managers. We must be effective stewards, and we must ensure that our elected representatives and the public have the opportunity to learn the truth about our river resources. Part of the job as scientist and manager must include a search for solutions to inefficiencies in government. Scientists are often unable or unwilling to translate their empirical information into a language that can be understood by elected representatives or the general public. Most of us have not been trained to communicate effectively with the public, and we are commonly not rewarded for doing so. Describing the contemporary condition of rivers to the public and proposing change is not in conflict with the traditional role of providing good science. We have to communicate what we know to the public, fishing industry, fishers and, especially, policy makers.

Our findings often lay dormant in agency reports, peer-reviewed journals, field notes, and symposia proceedings. We spend too much time talking to each other. Most of our literature cannot be understood by anyone but us and certainly not by most policy makers. Our knowledge of how rivers work is substantial, and we need to disseminate that knowledge much more widely.

We need the help of the media, and we need to assist the media to bring the crisis in our rivers to the attention of the public. We need to be part of the effort to build a solid base of political support for the wise multiple use and management of rivers. We need to convert knowledge of river ecosystems into useful information for action by decision makers.

In the Mississippi River basin, fishery agencies have agreed to work together to "overcome" the inefficiencies of government organization. Out of common concern came the Mississippi Interstate Cooperative Resource Agreement (MICRA). MICRA had it's official beginnings in 1989, when agreements were developed and signed by a majority of Mississippi basin state fishery management agencies. However, the movement began earlier, when an ad hoc committee of American Fisheries Society members formed a nucleus of managers that recognized the need for ecosystem perspectives when treating issues of interjurisdictional fisheries in the Mississippi River basin.

The Mississippi River ecosystem drains 41% of the contiguous United States, which includes all or portions of 28 states. The drainage basin is the largest in the United States and the fourth largest in the world (4.8 million km^2), exceeded only by the Amazon, Congo, and Nile basins. The drainage includes the Ohio, Missouri, Tennessee, Arkansas, and Red Rivers, among others, and the river discharges over 14,000 m^3/s of nutrient-rich fresh water into the Gulf of Mexico. Recent studies by the National Marine Fisheries Service indicate that the Mississippi River is probably the single most significant environmental factor influencing the Gulf of Mexico and its fisheries. This is one example of the importance of the ecosystem and emphasizes why the system should be of interest and concern to everyone in the basin, and in the country as well.

MICRA began from a concern among fisheries managers over how to coordinate management activities for species such as paddlefish, which have interstate ranges. Literally all of the management agencies in the basin realized we cannot manage fisheries in large interstate rivers in isolation. We must manage resources with an ecosystem perspective. MICRA was developed for just that reason. It provides an opportunity to begin formally opening lines of communication with other management groups in the basin who have interest and influence over what happens to the basin's water and habitat. By 1 September 1989 a core group of states had signed the agreement to initiate the process. During the remainder of 1989 and 1990, all 28 state natural resource agency directors in the basin signed onto the project. Early in 1991 the U.S. Fish and Wildlife Service was the first federal agency to join the MICRA signatories. At present, several federal resource agencies and two Indian tribes have signed the agreement.

The goal of MICRA is to improve the conservation, development, management, and use of interjurisdictional fishery resources in the Mississippi River basin through improved coordination and communication among the responsible management entities. This concept is not new, but it has never been attempted by resource agencies on such a grand scale.

MICRA will not duplicate any existing organizational network but will use its coordinative resources to enhance and maximize the efficiency of existing programs, institutions, and facilities. It will be managed by an interagency Steering Committee composed of personnel employed by member states and entities. Each signatory will have a seat on the steering committee. The Steering Committee will be chaired by one of the members on a

rotating basis. At a minimum, staffing will consist of a coordinator/executive secretary. Most technical work is to be conducted by the cooperating parties.

MICRA has several objectives for the improvement of the basin's aquatic resources, including:

1. Develop a formal framework and secure funding for basinwide networking and coordinating mechanisms that complement existing and emerging administrative entities. A strategic work plan is in place. The major problem to date has been to establish procedures that are practical and reliable.
2. Develop public information and education programs to disseminate information that supports fishery resource management in the Mississippi River basin. Initiate public information programs that will better educate our existing constituents and gain support of new ones. The public needs to become better informed of the importance of their rivers and of the potential they provide for all sorts of recreational opportunities.
3. Develop an information management program based on standardized methods for collecting and reporting fishery resource data, basinwide. MICRA should provide "one-stop shopping" for information on Mississippi River basin fisheries. Owing to various types of training and experience, fishery scientists and managers have developed many methods for sampling fish. Methods should be standardized so that sampling is comparable basinwide. This will enhance the use and sharing of fishery data.
4. Determine and document the socio-economic value of fishery resources and related recreation. Unfortunately, fisheries and related recreational resources have traditionally been considered far less valuable than development projects. This disparity has changed, and we need to gather information that fairly and equitably describes the economic and social importance of fish and wildlife resources.
5. Improve communication and coordination among entities responsible for fisheries resource management and traditional water development activities in the Mississippi River basin.
6. Identify and prioritize issues of concern in the Mississippi River basin for coordinated research that supports cooperative resource management. Periodic evaluation of issues and needs will ensure that MICRA does not get off on a one-issue tangent that would divert it from mainstream problems. Research funded or endorsed by MICRA will be research that addresses management needs.
7. Identify and coordinate fishery management programs to address species and habitat concerns from an ecosystem perspective. The key words here are *ecosystem perspective*. Many issues will arise that are locally significant; however, the primary mission will be on a broader ecosystem level.
8. Develop compatible regulations and policies for fishery management to achieve interstate consensus on allocation of fishery resources. This has been a traditional problem basinwide, although agencies in some parts of the basin have addressed this issue effectively. MICRA will promote standardization of regulations throughout the basin.
9. Protect native species and native biodiversity from invasion by exotic organisms by developing the protocol, policy, and regulations for disease control, introduction of non-native species, maintenance of genetic integrity, and maintenance and enhancement of indigenous species.
10. Preserve, protect, and restore fishery habitats basinwide through improved management and restoration of riverine and riparian habitats.

What has MICRA accomplished to date?

1. Established a coordinator's office with an executive secretary in Columbia, Missouri.
2. Established a bi-monthly newsletter entitled *River Crossings*.
3. Completed the Mississippi Basin Comprehensive Strategic Plan for Interjurisdictional Fisheries and the associated vision statement for restoring the river's fisheries.
4. Gained recognition by Congressmen Gunderson (Wisconsin) and Owens (Utah) that this strategy possibly could help meet the needs of the Nation's big rivers. Their legislation, introduced in 1992 as HR4169, would establish a national council, develop a national plan, and provide "test" funding for MICRA for 3 years.
5. Formed an interstate sturgeon and paddlefish work committee to provide the basis for management of these important species.

The effort undertaken to prepare papers for presentation at this symposium and to publish the proceedings will assist in the development of a database for MICRA and will highlight the challenges facing scientists, managers, resource decision makers, politicians, and concerned citizens.

Minnesota River Basin Assessment Project

by

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Abstract. The Minnesota River basin encompasses 44,300 km^2 in southwestern Minnesota, eastern South Dakota, and north-central Iowa. The river flows 597 km to its confluence with the Mississippi River at St. Paul, Minnesota. Original vegetation in the basin was tallgrass prairie, prairie wetlands, and hardwood forests. Agriculture dominates the land use throughout the basin. The Minnesota River has a negative effect on water quality in the Mississippi River with regard to sediment and nutrients. The fish community in the basin is composed of 84 native and 4 introduced species. The river supports a sport fishery for walleye (*Stizostedion vitreum*), channel catfish (*Ictalurus punctatus*), northern pike (*Esox lucius*), and flathead catfish (*Pylodictis olivaris*). A commercial fishery exists for common carp (*Cyprinus carpio*), buffalo (*Ictiobus* spp.), and freshwater drum (*Aplodinotus grunniens*). Fish consumption advisories for PCB's are in place for most species. Restoration planning began in 1989 with the initiation of the Minnesota River Assessment Project. The project is funded primarily by the Minnesota State Legislature through the Legislative Commission on Minnesota Resources. The Minnesota River Assessment Project is a multidisciplinary investigation of the physical, chemical, biological, and land-use characteristics of the basin with the goal of recommending Best Management Practices (BMP's) to achieve water quality goals. Implementation of recommendations will be directed by a citizens advisory committee made up of 30 individuals with diverse backgrounds. The citizens advisory committee will target its efforts at addressing runoff and sedimentation.

The Minnesota River is the largest tributary to the Mississippi River in Minnesota. The river begins at the South Dakota–Minnesota border and flows 597 km before emptying into the Mississippi River at St. Paul, Minnesota (Fig. 1). Average gradient in the stream is 0.2 m/km. The entire basin covers about 44,300 km^2 in Minnesota, South Dakota, and Iowa.

The Minnesota River is often referred to as Minnesota's "forgotten river" and is described as a resource in trouble, which is far different from the descriptions provided by early explorers. In the 1770's, J. Carver (1776) described the river as "most delightful country abounding with all the necessaries of life that grow spontaneously." In 1823, W. Keating (1825) described the river bed as "chiefly white sand," implying the water was clear enough to see bottom. In the 1830's, Featherstonaugh (1970 reprint) travelled the river, known then as the Minnay Sotor by the Sioux. He commented on the vast areas of wetlands he was able to see while paddling. Today that would be nearly impossible given the deeply cut vertical banks.

Geologic Characteristics

The Minnesota River is small compared with its expansive valley, nearly 8 km wide and 90 m deep in places. The river valley was carved by Glacial River Warren as it discharged from the south end of Glacial Lake Agassiz. As the elevation of Lake Agassiz dropped, a very small ridge appeared at Browns Valley, Minnesota, which became a continental divide. To the north the Red River of the North flows to Hudson Bay, and to the south the Minnesota River flows to the Mississippi River.

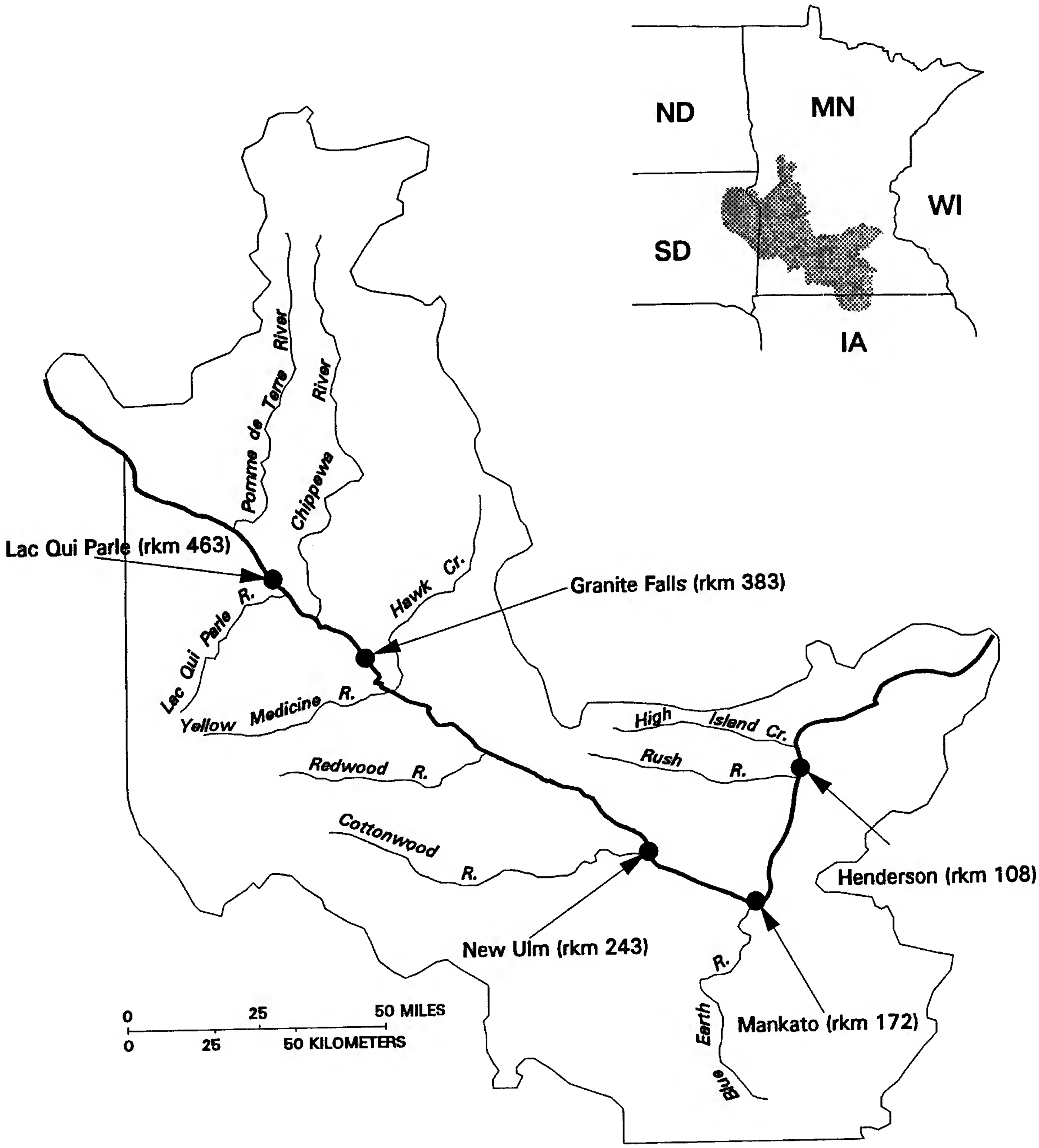

Fig. 1. The Minnesota River Watershed, showing major tributaries.

As the flow of Glacial River Warren receded over several thousand years, some distinct land features began to emerge. In the upper reaches of the valley, three lakes were formed as the alluvial fans of tributaries built up to form natural impoundments. Big Stone Lake was formed by the alluvial fan deposited by the Whetstone River (river kilometer [rkm] 533) coming from the west in South Dakota. Marsh Lake arose from the alluvial fan deposited by the Pomme de Terre River (rkm 488) coming from the hills and lake country to the north. Lac qui Parle Lake was formed as the result of the fan deposited by the Lac qui Parle River (rkm 464) coming from the southwestern prairies.

The river flows out of Lac qui Parle Lake through Precambrian granitic and metamorphic

rocks, Cretaceous shale and sandstone, and Pleistocene glacial deposits for 286 km in a southeasterly direction. At Mankato, Minnesota (rkm 178), the river makes an abrupt turn to the northeast to the confluence with the Mississippi River. Here, the channel is cut through lower Paleozoic sandstone, shale, dolomite and limestone, and overlying glacial deposits.

A unique feature of the watershed is the Coteau des Prairie in the southwest sector of the basin. The Coteau is a plateau that rests on the remains of an ancient mountain range. This plateau is 150–250 m higher than the otherwise flat to gently rolling prairie.

The original vegetation in the western two-thirds of the basin was tallgrass prairie and prairie wetlands. The eastern third of the basin was covered with hardwood forests. Floodplains of the Minnesota River and the lower reaches of the tributaries were forested with cottonwood, willow, and silver maple.

Existing Conditions

Today, the Minnesota River and its watershed are in some ways similar to the area in presettlement days and in other ways very different. The lower 384 km of the river are free from major modifications and are free-flowing. At rkm 408 and 413 there were small waterfalls that had been dammed for hydroelectric generation. The natural dams created by sediment deposition at Big Stone, Marsh, and Lac Qui Parle lakes were further developed with larger structures.

Land use in the basin has changed to predominately agricultural and urban use. Wetlands have been drained by installing drain tiles and ditches, and streams have been channelized and dammed.

Today, the Minnesota River has a serious negative effect on water quality in the Mississippi River. State and federal water quality standards for turbidity, unionized ammonia, and dissolved oxygen are frequently violated in the lower Minnesota River. These violations are probably due in large part to nonpoint pollution sources.

Restoration Planning

Comprehensive planning for the restoration of the river began in 1989 with the initiation of the Minnesota River Assessment Program (MRAP). Before 1989, data collection, and resource management activities and responsibilities were fragmented and often contradictory. The mission of the MRAP is to assess water quality, water quantity, sediment chemistry, aquatic communities, and current land uses in the Minnesota River basin. One objective of the project is to develop specific water quality goals and then to implement programs and Best Management Practices (BMP's) throughout the basin to achieve those goals.

The MRAP is a cooperative project funded primarily by the Minnesota State Legislature through the Legislative Commission on Minnesota Resources. Additional funding has come from the following cooperators: U.S. Geological Survey, U.S. Environmental Protection Agency, U.S. Soil Conservation Service, Minnesota Pollution Control Agency, Minnesota Department of Natural Resources, Minnesota Board of Water and Soil Resources, Minnesota Extension Service, Mankato State University, Gustavus Adolphus College, St. Olaf College, University of Minnesota, University of Minnesota–Duluth Natural Resources Research Institute, Soil and Water Conservation Districts, Metropolitan Waste Control Commission, Metropolitan Council, and several joint powers, boards, and other local units of government (water management organizations, watershed districts).

The structural organization of the MRAP consists of a steering committee that coordinates and directs the activities of four subcommittees. Each of the four subcommittees is further divided into specific components.

The MRAP is in its fourth and final year of assessment. Results presented in this paper are preliminary, as data are still being collected and analyzed. The final project report will include a synthesis of all components presented in a Geographical Information System (GIS) database with analysis and recommendations.

Restoration efforts will be coordinated by the Minnesota River Implementation Program (MRIP). The Minnesota River Implementation Program is composed of a Citizens Advisory Committee and a Technical Advisory Committee; each is made up of a diverse membership, representing the entire basin and a multitude of interests.

This report is a compilation of progress reports submitted by principal investigators of each of the study components (Table 1).

Table 1. Principal investigators, affiliation, and study component responsibility in the Minnesota River Assessment Project.

Principal investigator	Affiliation	Responsibility
Wayne Anderson	MPCA[a]	Project manager
Tim Larson	MPCA	Project coordinator
Greg Payne	USGS[b]	Physical/chemical
Joe Magner	MPCA	Hydrology
Mike Meyer	MWCC[c]	Metropolitan studies
Paul Wotzka	MDA[d]	Pesticides
Jack Arthur	USEPA[e]	Biology/toxics
Chris Kavanaugh	MDNR[f]	Biology/toxics
Pat Bailey	MPCA	Fish community
Jack Enblom	MDNR	Fish community
Steve Mercurio	MSU[g]	Fish physiology
Beth Proctor	MSU	Sediment chemistry
Jack Arthur	EPA	Sediment toxicity
Carl Richards	UM-NRRI[h]	Algal communities
Jim Zischke	SOC[i]	Macroinvertebrates
Henry Quade	MSU	Land use
Mary Mueller	MBSWR[j]	Land use
Gary Wehrenberg	SWCD[k]	Land use
Nick Pearson	SCS[l]	Land use
Kathy Svanda	MPCA	Data management
Ron Jacobson	MPCA	Modeling
Lynne Kolze	MPCA	Implementation

[a]Minnesota Pollution Control Agency.
[b]U.S. Geological Survey.
[c]Metropolitan Waste Control Commission (Minneapolis, St. Paul).
[d]Minnesota Department of Agriculture.
[e]U.S. Environmental Protection Agency.
[f]Minnesota Department of Natural Resources.
[g]Mankato State University.
[h]University of Minnesota—Natural Resources Research Institute.
[i]St. Olaf College.
[j]Minnesota Board of Soil and Water Resources.
[k]U.S. Soil and Water Conservation District.
[l]U.S. Soil Conservation Service.

Physical and Chemical Monitoring Subcommittee

Hydrology

Flow mechanics in the basin are controlled by multiple forces. Precipitation, evaporation, surficial aquifers, and deep aquifers play a part in the natural hydrology of the watershed. Settlement and subsequent development of the watershed have altered the hydrology.

Average annual precipitation increases from west to east, while evaporation decreases. Consequently, runoff and recharge increase west to east. Before agricultural development, most precipitation in the basin was stored in wetlands and in the top 3 m of soil. Groundwater recharge took place as soil water moved vertically to the aquifer or laterally to lakes and wetlands and then percolated down to the aquifer.

Manmade drainage systems now move the water off the uplands and rapidly deliver it to the river. Most of the wetlands have been drained, small streams channelized, and new streams (ditches) developed to move the water.

Instream flow varies by several orders of magnitude among and within years, depending on precipitation. Between 1989 and 1990, flows at rkm 108 varied from less than 500 cfs to more than 4,100 cfs (Fig. 2). Base flow is due in large part to springs in the bed or on the banks of the river. These springs tend to have relatively stable flows.

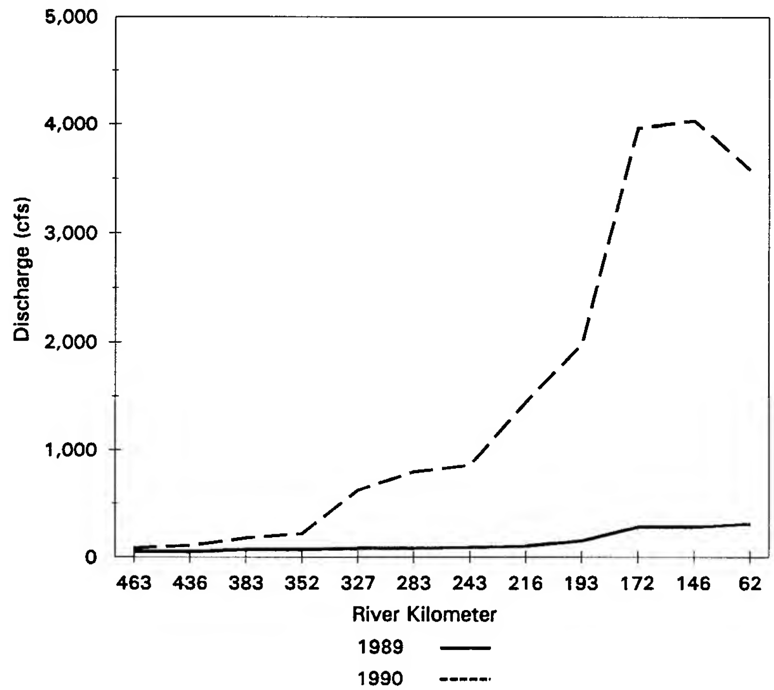

Fig. 2. Instantaneous discharge (cfs) in the Minnesota River in August 1989 and August 1990.

Physical and Chemical Monitoring

The objectives of physical and chemical monitoring are to (1) identify sources and loadings of nutrients, suspended sediment, biochemical oxygen demand, and organic carbon in the river; (2) calculate the movement of sediment and associated pollutants between points on the river; and (3) identify areas of bank erosion and associated deposition of sediment to determine the magnitude and impact of loadings of sediment within the river channel versus from upland areas.

Physical and chemical characteristics were monitored at 11 mainstem sites, 10 tributary sites, and 3 reservoir sites (Table 2). Monitoring began in 1989 and continued through 1992.

Loadings and concentrations of nutrients and sediments were much higher than expected considering the size and gradient of the mainstem. Concentrations of nutrients, specifically nitrates, increased in a downstream progression. Concentration of chlorophyll *a*, attributable mainly to algae, in the river exceeded normal levels and also increased in a downstream progression. Coliform bacteria, of human and animal origin, also exceeded normal levels.

Although preliminary at this point, the hypothesis is that dramatic alteration of drainage within the basin from ditching and tiling activities probably increased concentrations and total loading of nutrients in the river. The Blue Earth River (rkm 180) seems to be the most significant contributor of nutrients to the Minnesota River and is currently being studied intensively to identify sources of nutrient loading.

Land Use Subcommittee

More than 75% of the land use within the Minnesota River basin is agricultural (row crops—corn, soybeans, sugar beets). The number of animal feedlots is decreasing; however, the size of individual feedlots, particularly hogs and poultry, is increasing within the basin. Open ditch and tile drainage systems are found on more than one-third of the cultivated land, contributing soil and nutrients to the river (King 1985).

The Minnesota River basin can be separated into 1,208 minor watersheds that make up the surface water flow to the river system. Of these, 1,113 are in Minnesota, 18 in Iowa, and 77 in South Dakota.

Any activity within a watershed has the potential to affect water quality and biotic integrity within the watershed, and what happens in minor watersheds may ultimately have an effect in the mainstem. The land use subcommittee is studying existing land use characteristics within the basin on the four levels described below.

Table 2. Mainstem and major tributary sampling stations used in the Minnesota River Assessment Project.

Site name	River kilometer
Mainstem	
Lac Qui Parle	463
Montevideo	436
Sacred Heart	383
Delhi	352
Morton	327
Fairfax	283
New Ulm	243
Courtland	216
Judson	193
Mankato	172
St. Peter	146
Henderson	108
Tributaries[a]	
Chippewa River	442
Yellow Medicine River	393
Hawk Creek	381
Redwood River	349
Cottonwood River	232
Watonwan River	183
Le Sueur River	182
Blue Earth River	180
Rush River	109
High Island Creek	98

[a] River kilometer given is at the confluence with the Minnesota River.

Level I

Level I of land use is an examination of the nonpoint source pollution potential (NPSPP) model and the river continuum concept (Vannote et al. 1980). The model was developed by Peterson (1991) using aquatic ecoregions (Omernik 1987) and water quality data (Fandrei et al. 1988). The model is useful as a planning tool for identifying minor watersheds that may be significant contributors of nutrients to the mainstem.

The NPSPP model classifies minor watersheds within each ecoregion by percent area of land use, water orientation, soil texture and hydrologic groups, and slope parameters. These variables were correlated with 10 water quality parameters to generate a list of potential nonpoint source pollution indicators. The model assigns each minor watershed to 1 of 10 categories (1–10, 11–20, 21–30, ... 91–100). The 1–10 category has the lowest NPSPP, while 91–100 has the highest. Because the model uses an assigned rank, the overall distribution of categories throughout the basin is uniform. However, within a major watershed (tributary to the mainstem), there is often considerable variation.

A weakness of the model is that it does not take into account current land management practices. A minor watershed with high NPSPP may actually have excellent water quality if BMP's have been applied aggressively. Conversely, a minor watershed with lower NPSPP may have poorer water quality without BMP's.

Level II

The objective at Level II is to identify and recommend the most economical and cost-effective BMP's or resource management systems that will alleviate water quality problems caused by agricultural practices. The U.S. Soil Conservation Service is evaluating 10 minor watersheds using AGNPS and GLEAMS, as well as several other computer models.

Preliminary data on one of the minor watersheds indicate the use of BMP's on 80% of the watershed will reduce phosphorus loading by at least 50%. Cost analysis and participation by landowners are being investigated.

Level III

Local Soil and Water Conservation Districts within the basin have been applying a four-step process to 37 minor watersheds throughout the basin to identify land use characteristics. The process includes walking each of the minor watersheds to obtain field data, interviewing landowners within the watershed to determine existing land use practices, developing detailed land use maps, and developing a database.

Watersheds were selected in a systematic manner. The 10 watersheds studied in Level II were also included in Level III. An attempt was made to select additional minor watersheds that represented a cross section of existing conditions within the watershed. Another factor in choosing minor watersheds for study was the ability of the local soil and water conservation districts to cooperate.

This methodology provided accurate maps and an opportunity to inform and educate landowners about the project and the problem of nonpoint source pollution. However, the cost is very high (about $3,500 per watershed).

Within the group of watersheds selected for study, there was tremendous variability across the measured characteristics (Table 3). We wanted to study more minor watersheds and to

Table 3. Land use characteristics in 32 minor watersheds.

Variable	Range	Average
Area (km^2)	11.6–75.3	30.8
Main channel length (km)	0.34–35.0	10.2
Total channel length (km)	0.34–39.6	14.9
Channel slope (m/km)	0.17–13.2	2.3
Whole Watershed Data		
Wind erodible soils (%)	0–85	14.3
Water erodible soils (%)	0–98	32.5
Wind and water erodible soils (%)	5–99	50.3
Area tiled (%)	0–60	24.5
Open tile intakes	0–38	9.0
Erosion control structures/2.5 km^2	0–2	
Terraces/2.5 km^2	0–3	
Field windbreaks/2.5 km^2	0–2.4	
Field windbreak length (m/2.5 km^2)	0–1,426	249
Waterways/2.5 km^2	0–4.5	0.7
Waterway length (m/2.5 km^2)	0–2,270	240
Percent pasture	0–10	1.2
Percent green belt	0–45	5.1
Percent row crop	30–90	64.5
Percent small grain	1–25	10.0
Percent long-term set aside	0–25	3.4
Percent lake	0–30	2.0
Percent wetland	0–15	2.6
Percent urban	0–22	1.3
Number of feedlots	0–17	3.5
Number of farmsteads	7–54	27.1
Number of septic outlets	0–40	8.7
Number of promiscuous dumps	0–37	3.8
Number of unique areas	0–29	2.9
Riparian Integrity		
Percent pasture	0–75	3.8
Percent green belt	0–99	26.8
Percent row crop	0–85	43.2
Percent small grain	0–35	8.2
Percent long-term set aside	0–45	4.6
Percent lake	0–10	0.5
Percent wetland	0–90	6.1
Percent urban	0–20	0.7
Number of feedlots	0–7	0.8
Number of farmsteads	0–14	3.3
Number of dumps	0–20	2.2
Number of gullies	0–24	2.8

build in some replication; however, the time and cost were prohibitive.

Level IV

This component involves using infrared aerial photography on the same 10 watersheds examined in Level II. Aerial infrared photos were taken in spring 1992 before leaves were present. Ground photos were taken concurrently to aid in aerial photo interpretation. A mosaic of all aerial photos will be made; landscape features will be identified, mapped on mylar sheets, and recorded in digitized form. We hope this level of assessment will prove as reliable as and more economical than Levels II and III.

Biological Monitoring Subcommittee

Sediment Chemistry

During the last 15 years, total suspended solids in the lower Minnesota River have been six times greater than those in the Mississippi River at their confluence (MPCA files). Contaminants such as heavy metals and PCB's often associate with smaller particles in suspended solids and sediments (Oliver 1989).

Suspended solids, sediments, sediment pore water, and mussels were collected at four mainstem and five tributary sites once during spring and once during summer 1990. Suspended solids were analyzed for pH, percent organic matter, nickel, cadmium, lead, copper, zinc, and chromium. Zinc was the most abundant of the heavy metals found, and cadmium was the least abundant.

Ambient Toxicity

Toxicity tests frequently show good correlation with elevated instream pollutants and downstream persistence (Ankley et al. 1990). The objective of this component of the study is to determine if ambient toxicity can be demonstrated in Minnesota River surface water and sediments. Thirteen mainstem sites, eight tributary sites, and four reservoir sites were selected. These sites were chosen based on the following criteria: good road accessibility and availability of stream sediment, area to launch a small boat, and proximity to physical and chemical subcommittee monitoring sites.

Ambient water and sediment samples were collected in midchannel to avoid shoreline disturbances. Samples were collected during five periods in 1989 and 1990 to cover all four seasons and to coincide with other sampling activities. Anion and cation concentrations were determined for each of the samples.

Two standardized test procedures were applied to the surface water and sediment pore water. *Ceriodaphnia*, a microcrustacean, and *Selanastrum*, a green alga, were the test organisms. *Ceriodaphnia* test procedures are described by Horning and Weber (1985), and *Selanastrum* test procedures are described by the U.S. Environmental Protection Agency (1989).

Toxicity to *Ceriodaphnia* was found at 5 of the 25 sampled sites. The most highly toxic sites were found near the mouth of the Minnesota River and in Lac Qui Parle Reservoir. Mainstem locations upstream from rkm 17 and the eight tributary locations were nontoxic, but three of the four reservoir sites were toxic.

Toxicity to *Selanastrum* was found at 8 of the 15 sampled locations. Toxicity was found at all sites in the mainstem between rkm 336 and the mouth and at both sampled reservoir sites. None of the five sampled tributaries was toxic. The most toxic site to *Selanastrum* was found in Lac Qui Parle Reservoir.

Reservoir sites had higher concentrations of total nutrients in sediment pore water, mainstem sites showed higher concentrations of nitrite, and tributary sites had higher concentrations of nitrate. Four locations—two mainstem (Fort Snelling and I-35W Bridge) and two reservoirs (Rapidan and Lac Qui Parle)—had the highest concentrations of ammonia and total phosphate. Three mainstem locations (I-35W Bridge, Judson, and Courtland) had nitrite levels more than 100 times higher than the other sites. Four tributary locations (Le Sueur, Blue Earth, Watonwan, and Rush rivers) had sediment nitrate concentrations 2–10 times greater than the other locations. Ammonia, nitrate, total phosphate, and iron showed a progressive increase in downstream mainstem locations.

Algal Communities

The composition and abundance of algal communities in streams reflect characteristics of the surrounding watershed, riparian zone, and channel morphology. These features influence the physicochemical conditions of water and substrate

conditions available for algal colonization and growth. Consequently, algal communities are good indicators of stream health and can serve as important biological monitors. The variation in community composition that exists among subhabitats within streams and among individual streams (Douglas 1958; Krecji and Lowe 1986; Pringle 1987) can be used as a tool to understand problems that exist within the watershed. Variation in community composition can be attributed to differences in the nutrient availability of surface waters (Eminson and Moss 1980), size and biological activity of substrata (Miller et al. 1987; Carlton and Wetzel 1988), and substrate type (Stevenson and Hashim 1989).

In situ algal bioassays were conducted at one mainstem and four tributary sites in 1990. Bioassays were done with nutrient-diffusing artificial substrata similar to those of Fairchild and Lowe (1984). Sites were chosen that were similar in water velocity and shading. Four potentially limiting nutrient treatments and a control were attached to a 1.5-m-long, 2- × 6-cm board (Bushong and Bachmann 1989). Six boards were placed at each site, 10–15 m apart. After 7 days, three boards at each site were randomly chosen and analyzed for periphyton. The three remaining boards were removed and periphyton sampled after 14 days.

Chlorophyll *a*, organic weight, inorganic weight, and fine sediment accumulation were measured in the laboratory. Turbidity, water velocity, and maximum-minimum temperatures were monitored at each site.

The proportion of the substrate composed of particles less than 2.4 mm in diameter ranged between 47 and 100% in mainstem sites and between 33 and 75% in tributary sites. Iwamoto et al. (1978) and Rivier and Sequier (1985) stated that the presence and addition of fine sediments (<2.4 mm) to lotic systems can have strong effects on biotic communities and functional parameters.

Existing algal communities were identified on hard substrates at six sites. Thirty-nine taxa of diatoms, green algae, and bluegreen algae were found. Diatoms were dominant at all sites (66–92%), represented by 16 taxa. The most abundant diatoms were *Cyclotella* spp. and various pennates. Twenty-three algal taxa were identified. The most abundant were the green algae *Ankistrodesmus* spp., and *Scenodesmus* spp.

The greatest differences among the sites seemed to be partly attributable to available substrate conditions. Sites with a diversity of substrates ranging from cobble and gravel to detritus and woody debris had a greater diversity of algal taxa.

The relative influence of nutrients on algal production in this study was low. The phosphorus and nitrogen-phosphorus treatments had statistically significant stimulatory effects on chlorophyll *a* and biomass accrual; but the overall effect was small. Water chemistry data indicate that the streams all have relatively high concentrations of nitrates and phosphorus, but N:P ratios varied considerably.

The variation in overall algal biomass and production among sites may be attributed to differences in quantity of available colonists, and consequent colonization and deposition of algal material. Other studies of midwestern streams have implicated water temperature and light as being more important than nutrients in controlling algal production (Bushong and Bachmann 1989; Munn et al. 1989). Water temperatures did not vary more than 3° C during this study and did not seem to be a controlling factor. However, because of the high levels of turbidity, light may have been limiting. Turbidity values recorded were as high or higher than values observed by Munn et al. (1989) to impair algal production (>10 NTU). In addition to the reduction of light, suspended sediments accumulated directly on the artificial substrates. There were also at least two storm events that carried elevated sediment loads that could have scoured algae from the test substrates.

Sampling and analysis of algal communities is continuing at 20 sites on minor watersheds. Development of diverse periphyton communities throughout the Minnesota River basin seems to be limited by lack of stable substrates, high turbidity, high sediment loads, and predominance of fine sediments.

Macroinvertebrates

Benthic macroinvertebrates are important indicators of water quality (Hynes 1970). Aquatic macroinvertebrates are found in nearly all stream habitats and display a wide variety of functional feeding characteristics (Merritt and Cummins 1984). Environmental requirements and pollution tolerance information are available for most taxa. These factors make aquatic macroinvertebrate indices useful in assessing water quality.

Macroinvertebrate data from the Minnesota River have been collected by several investigators over the years (Kirsch et al. 1985). Previous investigations focused on only a small portion of the

Table 4. Macroinvertebrate metrics[a] applied to sampling stations in the Minnesota River basin.

Community metrics	Taxonomic group metrics
Richness	Functional feeding group ratio
Shannon-Weaver Diversity Index	Number and percent of mayflies
Equitability Index	Number and percent of caddis flies
Community Similarity Index	Number and percent of dipterans
Community Loss Index	Ratio of mayflies, stoneflies, caddis flies
Macroinvertebrate Biotic Index	

[a]Plafkin et al. 1989.

river. The objective of this component of the project was to assess the level of impairment among macroinvertebrate communities throughout the Minnesota River basin.

Benthic macroinvertebrates were collected at 9 stations on the mainstem, 10 major tributaries, and 22 minor watersheds. Benthic macroinvertebrate sampling stations coincided with sampling stations used for other project components.

Sampling gear consisted of hand picking, kick-nets, and artificial substrate sampling (Hester and Dendy 1962). Sampling was done in summer and fall. Replicate samples were taken on some sites on the mainstem and tributaries.

Eleven metrics are being used to assess the health of the macroinvertebrate community at each site (Plafkin et al. 1989). Six metrics apply to the whole community, and the other five apply to specific taxonomic or functional groups (Table 4). In addition to the biotic metrics, the habitat quality of each site was quantified using a Qualitative Habitat Evaluation Index (QHEI) developed by the Ohio Environmental Protection Agency (1987).

In the 1989 sampling, chironomids dominated at the most-downstream location (Henderson, rkm 108) and at the two most-upstream sites (Upper Sioux, rkm 382; and Lac Qui Parle, rkm 454). At all other mainstem stations, the communities were dominated by caddis flies. The most common caddis fly genus was *Hydropsyche* spp. *Cheumatopsyche* spp. was collected in large numbers at Courtland (rkm 216), as was *Cyrnellus* spp. at Lac Qui Parle. The most common chironomid genus on the mainstem was *Glyptotendipes*, which was collected at all stations.

Benthic community composition at tributary sampling sites in 1989 varied more than at mainstem sites. Caddis flies dominated at five sites, chironomids at three, and mayflies at two. Other major insect groups were generally found in higher proportions than on the mainstem.

In the 1990 survey, four mainstem sites were dominated by caddis flies and midges, and one site was dominated by mayflies. Chironomids again dominated at Henderson, Upper Sioux, and Lac Qui Parle. *Glyptotendipes* spp. was the most abundant midge at five locations.

Community composition of benthos on the tributaries was again more variable than on the mainstem in the 1990 survey. Caddis flies were dominant at five locations, mayflies at two, and midges at three locations.

On the basis of richness, diversity, and macroinvertebrate biotic indices, the 19 stations on the mainstem and tributaries were categorized in relation to the effects of pollution. All stations sampled in 1989 and 1990 were affected by pollution, as determined by the three metrics listed above (Table 5). Henderson, Upper Sioux, and Lac Qui Parle were the mainstem stations most affected, while the Chippewa River was the most affected tributary.

Comparison of benthic diversity indices with QHEI indicates a relation between the two in the tributaries. As QHEI increased, diversity increased in 1989 and 1990. There was no such relationship observed in the mainstem sites. Perhaps the mainstem sites are more affected by variables other than habitat, with respect to macroinvertebrates.

Fish Physiology

Organic pollutants have the ability to induce liver mixed-function oxidase activities in fish (Brown 1976; Melancon et al. 1987). Polychlorinated biphenyls have been found in fish from the Minnesota River by the Minnesota Department of Health. Levels of PCB's were high enough to issue consumption advisories for sport-caught fish. From Granite Falls to the mouth of the river, the advisory for most fish is one meal per month.

The objective of this component of the study was to determine if PCB's alone or in combination with other organic pollutants in the Minnesota River were sufficient to have a significant effect on fish liver activities. An additional objective was to compare PCB levels found through arochlor analysis versus congener analysis.

Table 5. Macroinvertebrate richness, diversity, and biotic integrity (MBI) at 19 mainstem and tributary sites sampled in 1989–90.

Station	Richness		Diversity		MBI	
	1989	1990	1989	1990	1989	1990
			Mainstem			
Henderson	15	19	1.77	1.54	5.27	7.69
St. Peter	24	24	2.32	3.29[a]	4.93	5.05
Judson	34[a]	23	2.60	3.09[a]	5.92	5.45
Courtland	27[a]	24	2.61	2.82	5.33	5.55
Fort Ridgely	28[a]	23	2.21	1.47	5.11	4.37
Morton	32[a]	22	2.38	2.84	4.62	5.59
Delhi	27[a]	23	2.85	2.76	5.26	4.87
Upper Sioux	23	27[a]	1.63	2.17	7.93	7.21
Lac Qui Parle	12	22	2.47	1.11	5.54	3.56
			Tributary			
High Island Creek	21	17	2.78	2.62	4.62	4.67
Rush River	31[a]	19	4.10[a]	2.65	6.59	6.39
Blue Earth River	21	18	3.00[a]	3.35[a]	6.37	5.26
Le Sueur River	35[a]	22	3.54[a]	3.19[a]	5.23	3.84
Watonwan River	29[a]	31[a]	3.67[a]	4.04[a]	5.97	5.17
Cottonwood River	25	22	2.46	3.05[a]	7.91	4.76
Redwood River	29[a]	26[a]	3.30[a]	3.33[a]	5.88	5.69
Hawk Creek	24	22	3.17[a]	2.29	6.64	5.42
Yellow Med. Riv.	19	21	2.41	2.74	4.37	4.67
Chippewa River	17	19	2.40	2.00	6.85	8.46

[a] Considered affected.

Fish samples were taken from two tributary (Cottonwood and Blue Earth rivers) and two mainstem sites. Species collected included common carp, smallmouth bass, and sauger. Liver microsomal aminopyrine N-demethylase activities were measured, and the PCB analysis is ongoing.

Liver microsomal aminopyrine N-demethylase activity was higher at the Judson site (mainstem) than at all other sites in 1989. In 1990, liver enzyme activities in common carp samples were higher at the Cottonwood River site and lower at the Judson site.

Additional fish were collected in 1992 to test the hypothesis of high pollutant concentrations in low-flow years in the Minnesota River and high-flow years in the tributaries.

Fish Community

The Minnesota River basin provides an important fishery resource for southern Minnesota. Channel catfish, flathead catfish, walleye, sauger, and northern pike support most of the sport fishery in the streams of the basin. A commercial fishery exists for common carp, buffalo, and freshwater drum.

Comprehensive fisheries assessments throughout the basin are lacking. Kirsch et al. (1985) surveyed the mainstem Minnesota River from 1980 to 1982. The Minnesota Department of Natural Resources has assessed segments of the mainstem and some major tributaries. However, there has never been a comprehensive assessment of fish communities throughout the basin.

The index of biotic integrity (IBI) is an ecologically based index used to assess degradation in midwestern streams (Karr 1981). The method has been modified to assess degradation of streams in a variety of ecoregions throughout North America (Leonard and Orth 1986; Hughes and Gammon 1987; Ohio Environmental Protection Agency 1987; Miller et al. 1988; Steedman 1988; Fausch et al. 1990; Bramblett and Fausch 1991).

The regional fish fauna was examined by a team of Minnesota Department of Natural Resources and MPCA staff and ichthyologists from the University of Minnesota (Professors J. Underhill and J. Hatch). This team reviewed and evaluated the metrics proposed by Karr (1981), Fausch et al. (1984), and Karr et al. (1986) and their underlying rationale. The team developed replacement metrics or rationale where necessary to conform with

Table 6. Proposed Index of Biotic Integrity metrics to describe the fish communities in the Minnesota River basin.

Metric 1	Total number of native species.
Metric 2	Number of darter species.
Metric 3	Number of sunfish species.
Metric 4	Number of sucker species (excluding white sucker) or number of minnow species (excluding common carp, creek chub, and fathead minnow) at sites <250 km^2 drainage area.
Metric 5	Number of intolerant species.
Metric 6	Proportion of individuals that are tolerant (white sucker, carp, fathead minnow, creek chub, and black bullhead).
Metric 7	Proportion of individuals that are omnivores.
Metric 8	Proportion of individuals that are specialized insectivores.
Metric 9	Proportion of individuals that are top carnivores or number of top carnivore species at sites <500 km^2 drainage area.
Metric 10	Catch per unit effort (time) by gear type.
Metric 11	Proportion of individuals that are simple lithophils.
Metric 12	Proportion of individuals with deformities, eroded fins, lesions, and anomalies.

conditions in the Minnesota River watershed (Table 6). Whenever changes were made, the original intent of Karr's metric was adhered to as much as possible. Metrics 6, 8, and 11 were modified for all stream sizes. Metrics 4 and 9 were changed for streams with small (<260 km^2 and <520 km^2, respectively) drainage areas because Karr's conditions did not exist in those streams.

Development of Minnesota River IBI scores required compilation of a reference database indicating the highest attainable fish community characteristics for the watershed. The reference database was compiled in a two-part process. The first part involved examining historical information from 650 site collections conducted by Minnesota Department of Natural Resources, J. Underhill (University of Minnesota), and K. Schmidt (private collector). The second part was composed of collections made in 1990 at 45 sites considered to be least affected.

For each site collection in the historical database, the number of individuals of each species collected, sampling gear used, drainage area of the watershed above the sampling site, and location of the sampling site were considered in determining if the site collection should be used for calculating IBI metric expected values. Sites were excluded from the database if they were within 5 km of a much larger river or lake or were influenced by a dam or other obstruction. Because fish migrate from larger habitats into adjacent smaller habitats, sites close to a confluence may have fish community characteristics more representative of the larger stream or lake and would tend to elevate the maximum species richness line.

Reference sites sampled in 1990 were selected based on available information and field reconnaissance. Land use, riparian cover, pool-riffle presence, avoidance of point source pollution discharge, and overall similarity with other streams in the area were considered in selecting sites. The 45 sites were distributed throughout the basin and covered a diversity of stream habitats, from small headwater streams to the mainstem of the Minnesota River. These sites were considered to be some of the least-degraded stream segments in the watershed. However, all sites had been modified from their natural conditions by extensive human activities.

Fish were sampled using backpack, stream, or boom electrofishing equipment (Reynolds 1983), depending on stream size. All electrofishing equipment used adjustable, square-wave, pulsed DC current. Pulse width, frequency, voltage, and amperage were modified at each site to maximize efficiency for individual stream conditions. Flow, conductivity, dissolved oxygen, temperature, and QHEI measurements were made at each site. All captured fish were identified to species and examined for external anomalies. Voucher specimens and fish of uncertain identity were preserved in 10% formalin and submitted to the University of Minnesota.

Maximum species richness lines for metrics addressing the number of species present were determined graphically using the historical and reference (1990) databases. Expected values for metrics dealing with percent composition of the catch and for metrics 11 and 12 were determined only from the 1990 reference site database. Sampling techniques in the historical database varied widely, which could affect the relative abundance of species collected.

Drainage area is considered an adequate measurement of stream size and may be better than stream order (Hughes and Omernik 1981). Drainage area was also chosen because it was the information most readily available for streams within this basin. Alternative measurements of stream size, such as mean annual discharge or mean width, were not available.

In determining the 5, 3, and 1 scoring for each metric, the procedure described by Ohio Environmental Protection Agency (1987) was followed. The data were plotted against a $\log_{10}$ transformation of drainage area. The graph was examined to determine if there was a positive relation with drainage area and over what range of stream sizes this relation occurred. If a positive relation occurred through any range of stream sizes, a line was drawn to incorporate about 90% of the 1990 reference sites. The area beneath this line was then trisected equally. Where a positive relation was not found, an alternative trisection method was used. For these metrics, a horizontal 5% and 95% line was determined, and the area between them was trisected.

Sixty-four fish species representing 17 families were collected in 1990 (Table 7). Fifty-four species were collected in 13 boom electrofishing stations, 49 species from 16 stream electrofishing stations, and 30 species from 16 backpack electrofishing stations. The boom electrofishing stations had a higher percent composition (59.2%) of large fishes (excludes minnow, darter, and other small fish species) compared with the stream (18.7%) and backpack (6.5%) stations.

The IBI scores for the 1990 reference sites ranged from 20 to 56. The median score was 36, and the mean was 37.5. Karr et al. (1986) considered IBI values less than 34 (out of a possible score of 60) as representative of poor or very poor conditions.

Table 7. Fish species sampled at 45 reference sites in 1990[a], occurring in the historical data base, and reported in Underhill (1989).

Scientific name	Common name	Historical data	Underhill
Ichthyomyzon unicuspis	Silver lamprey [a]	x	
Lampetra appendix	American brook lamprey	x	x
Scaphirhyncus platorynchus	Shovelnose sturgeon [a]	x	x
Polyodon spathula	Paddlefish	x	x
Lepisosteus osseus	Longnose gar	x	x
L. platostomus	Shortnose gar [a]	x	x
Amia calva	Bowfin	x	x
Hiodon alosoides	Goldeye [a]	x	x
H. tergisus	Mooneye [a]	x	x
Anguilla rostrata	American eel [a]	x	x
Dorosoma cepedianum	Gizzard shad [a]	x	x
Campostoma anomalum	Central stoneroller [a]	x	x
C. oligolepis	Largescale stoneroller [a]	x	x
Carassius auratus	Goldfish	x	x
Cyprinella spiloptera	Spotfin shiner [a]	x	x
Cyprinus carpio	Common carp [a]	x	x
Hybognathus hankinsoni	Brassy minnow [a]	x	x
Luxilus cornutus	Common shiner [a]	x	x
Macrhybopsis aestivalis	Speckled chub	x	x
M. storeriana	Silver chub	x	x
Margariscus margarita	Pearl dace	x	x
Nocomis biguttatus	Hornyhead chub [a]	x	x
Notemigonus crysoleucas	Golden shiner	x	x
Notropis anogenus	Pugnose shiner	x	

Table 7. *Continued.*

Scientific name	Common name	Historical data	Underhill
N. atherinoides	Emerald shiner [a]	x	x
N. blennius	River shiner	x	x
N. dorsalis	Bigmouth shiner [a]	x	x
N. heterodon	Blackchin shiner	x	x
N. heterolepis	Blacknose shiner [a]	x	x
N. hudsonius	Spottail shiner [a]	x	x
N. rubellus	Rosyface shiner [a]	x	x
N. stramineus	Sand shiner [a]	x	x
N. texanus	Weed shiner	x	x
N. volucellus	Mimic shiner	x	x
Phoxinus eos	Northern redbelly dace [a]	x	x
P. erythrogaster	Southern redbelly dace	x	x
Pimephales notatus	Bluntnose minnow [a]	x	x
P. promelas	Fathead minnow [a]	x	x
Rhinichthys atratulus	Blacknose dace [a]	x	x
R. cataractae	Longnose dace	x	x
Semotilus atromaculatus	Creek chub [a]	x	x
Carpiodes carpio	River carpsucker [a]	x	x
C. cyprinus	Quillback [a]	x	x
C. velifer	Highfin carpsucker [a]	x	
Catostomus commersoni	White sucker [a]	x	x
Hypentelium nigricans	Northern hog sucker [a]	x	x
Ictiobus bubalus	Smallmouth buffalo [a]	x	x
I. cyprinellus	Bigmouth buffalo [a]	x	x
I. niger	Black buffalo	x	
Moxostoma anisurum	Silver redhorse [a]	x	x
M. carinatum	River redhorse	x	
M. erythrurum	Golden redhorse [a]	x	x
M. macrolepidotum	Shorthead redhorse [a]	x	x
M. valenciennesi	Greater redhorse	x	x
Ameiurus melas	Black bullhead [a]	x	x
A. natalis	Yellow bullhead [a]	x	x
A. nebulosus	Brown bullhead	x	x
Ictalurus punctatus	Channel catfish [a]	x	x
Noturus flavus	Stonecat [a]	x	x
N. gyrinus	Tadpole madtom [a]	x	x
Pylodictis olivaris	Flathead catfish [a]	x	x
Esox lucius	Northern pike [a]	x	x
Umbra limi	Central mudminnow [a]	x	x
Oncorhynchus mykiss	Rainbow trout	x	x
Salmo truuta	Brown trout [a]	x	x
Percopsis omiscomaycus	Trout-perch	x	x
Lota lota	Burbot	x	x
Fundulus diaphanus	Banded killifish	x	x
Culaea inconstans	Brook stickleback [a]	x	x
Morone chrysops	White bass [a]	x	x
Ambloplites rupestris	Rock bass [a]	x	x
Lepomis cyanellus	Green sunfish [a]	x	x
L. gibbosus	Pumpkinseed [a]	x	x
L. humilis	Orangespotted sunfish [a]	x	x
L. macrochirus	Bluegill [a]	x	x
Micropterus dolomieu	Smallmouth bass [a]	x	x
M. salmoides	Largemouth bass [a]	x	x
Pomoxis annularis	White crappie [a]	x	x
P. nigromaculatus	Black crappie [a]	x	x

Table 7. *Continued.*

Scientific name	Common name	Historical data	Underhill
Ammocrypta clara	Western sand darter	x	x
Etheostoma caeruleum	Rainbow darter [a]	x	x
E. exile	Iowa darter [a]	x	x
E. flabellare	Fantail darter [a]	x	x
E. nigrum	Johnny darter [a]	x	x
E. zonale	Banded darter [a]	x	x
Perca flavescens	Yellow perch [a]	x	x
Percina caprodes	Logperch	x	x
P. maculata	Blackside darter [a]	x	x
P. phoxocephala	Slenderhead darter [a]	x	x
Stizostedion canadense	Sauger [a]	x	x
S. vitreum	Walleye [a]	x	x
Aplodinotus grunniens	Freshwater drum [a]	x	x

[a] Found at 45 reference sites in 1990.

The poor biological conditions, as expressed by the IBI, of so many selected reference sites indicates that there may be a problem with either the sites or the scoring. Most of the low scores occurred at sites in streams with a drainage area less than 500 km^2. The sites chosen may not have been good reference sites. However, most of the Minnesota River headwater streams have been altered extensively, and these sites probably represent some of the best existing conditions in the basin. Also, some of the metrics used may not be applicable to small streams.

In 1991 and 1992, 37 headwater streams (minor watersheds examined by the Land Use Section) were sampled. Additionally, two major tributaries, the Redwood and Blue Earth rivers, were sampled longitudinally. Sampling on the major tributaries began at the mouth and continued upstream to near the source of sustained flow and included minor tributaries. The objective of this sampling was to determine the longitudinal IBI scores and to relate these scores with resource conditions in terms of habitat, water chemistry, and surrounding land use.

Data Management Subcommittee

Modeling

Mathematical models can be used to evaluate the cumulative effects of nonpoint source loadings from surface runoff by simulating pollutant transport through the river system, pollutant interactions, biochemical transformations, and the overall effect on the river's water quality. A comprehensive model is being developed using hydrological, land use, and water quality data collected in the Minnesota River watershed. This model will be used as an analytical tool for evaluating the spatial and temporal loadings from nonpoint source pollution and their effect on water quality in the Minnesota River.

The Hydrologic Simulation Program-FORTRAN, supported by the U.S. Environmental Protection Agency Center for Exposure Assessment Modeling (Ambrose and Barnwell 1989), will be used to simulate the effect of nonpoint source loadings in the mainstem. The Hydrologic Simulation Program-FORTRAN is a comprehensive model of watershed hydrology and water quality that integrates runoff processes from land surfaces with the instream physical and chemical water quality processes. The model is designed to simulate a time series of runoff flow rate, sediment load, oxygen-demanding organics, and nutrient concentrations, along with a time series of water quantity and quality at any point in the watershed. Model output can be processed through a frequency and duration analysis routine for summation and evaluation of the fate and transport of pollutants through the river system. Because the Hydrologic Simulation Program-FORTRAN is a general purpose model, its output can be used to support more specialized hydrodynamic models, such as the Water Analysis Simulation Program, for closer examination of special water quality situations.

Once the Hydrologic Simulation Program-FORTRAN model is set up to represent the Minnesota River watershed, each land segment will be modeled to generate runoff and pollutant loads per unit area to the stream channel. The runoff and pollutant loads to each reach will be determined by multiplying the unit area runoff and pollutant loads by the area of each land segment tributary to each channel reach. These calculations for each reach, in conjunction with modeling the instream hydraulic and water quality processes, will result in simulation of the entire watershed.

Monitoring data from the physical and chemical component of the study will be used to verify the model's ability to simulate observed conditions. The model will then be used to investigate the expected outcomes of applying various land management practices to reduce nonpoint source pollution loadings.

Citizen Involvement

Improving water quality on a large scale can only be accomplished through active citizen participation (Pinkerton 1991). The MRAP recognized the importance of citizen involvement at the outset of the project. As the data collection activities conclude, the Minnesota River Implementation Program is getting underway.

The initial step in the Minnesota River Implementation Program was a series of public meetings held throughout the basin to solicit input and information from concerned citizens. While these meetings were not well-attended by the public, some important messages were delivered to the regulatory agencies. There was a strong feeling that enough money has been spent on determining there are problems; now is the time to start spending money to fix the problems.

The goal of the Minnesota River Implementation Program is to develop a comprehensive strategy for improving water quality in the river through three avenues: a citizens advisory committee, an interagency technical advisory committee, and the general public. The citizens advisory committee is made up of 30 people who represent diverse organizations throughout the basin and who will have significant involvement in the development of an overall strategy for improving water quality. The technical advisory committee will be the liaison group between the MRAP and the citizens advisory committee. Finally, the general public will ultimately carry out any recommendations put forth by the citizens advisory committee.

Development of an implementation strategy is just getting underway. Actual implementation should be underway by 1994. Until citizens advisory committee recommendations are implemented, agency program managers are being asked to consider targeting existing programs and resources to address water quality problems in the Minnesota River basin.

The Minnesota Board of Soil and Water Resources has committed 50% of the statewide Reinvest in Minnesota Reserve funds to the Minnesota River basin. The Department of Natural Resources–Section of Fisheries has recently completed a comprehensive fish survey of the main-stem Minnesota River. Other agencies are currently discussing reallocating funds to the Minnesota River basin. At this writing there are no results to report.

In the past few years several groups have organized and are spearheading river issues. These groups are growing in size and number and will prove to be important players in the implementation of water quality improvements.

Conclusion

The Minnesota River basin study is serving as a model of comprehensive watershed investigation and planning in Minnesota. A tremendous amount of information has been compiled that will answer many questions about water quality and biotic integrity in the watershed. The MRAP and Minnesota River Implementation Program programs will serve as the catalyst for additional studies, such as a comprehensive creel, recreational use, and economic benefit survey of the entire river.

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Aquatic Resources of the St. Croix River Basin

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Abstract. The St. Croix River is a sixth-order stream draining a 20,018-km^2 area in east-central Minnesota and northwestern Wisconsin. The 276-km mainstem (average gradient = 0.46 m/km) includes a 1,889-ha natural lake at its mouth and two small reservoirs created by the 3.7-km-high Gordon Dam and the 18-km-high St. Croix Falls Dam. The latter dam, which has a discharge area of 16,162 km^2 and an annual mean discharge of 120 m^3/s (water years 1902–91), is a barrier to upstream fish migration. The basin has a total of 134 dams on 1,770 tributary streams (9,004 km total length) and has 628 open lakes that are greater than or equal to 0.4 ha (41,012 ha total surface area). Historically, 110 species of fish representing 24 families have been identified from the St. Croix River basin. Six species have been introduced, while seven other native species have not been collected since 1974. One species (*Ammocrypta asprella*) is on Wisconsin's endangered species list, and eight species are on its threatened list. With a minimal commercial fishery, the sport fishery for walleye, sauger, smallmouth bass, brown trout, and lake sturgeon constitutes almost all of the economic value of the fishery. There are 39 freshwater mussel species in the basin. Two species (*Lampsilis higginsi* and *Quadrula fragosa*) are on the federal endangered species list. Nine species are considered endangered and three threatened in Wisconsin. Aquatic insect surveys on the St. Croix River and a few tributaries identified invertebrates representing 332 taxa, 235 genera, and 100 families. In 1968, with the enactment of the National Wild and Scenic Rivers Act, 165 km of the St. Croix River and 157 km of the Namekagon River became one of the first eight rivers to become part of the National Wild and Scenic Riverway system. In 1972, 87 km of the lower St. Croix River were added to the system. The water quality of this scenic riverway is generally good and is one of the outstanding recreational resources in the Midwest.

Historically, Native Americans used the St. Croix River to travel between Lake Superior and the Mississippi River basin. During the eighteenth century, the river became a major route for French and English fur traders. In the nineteenth century, the St. Croix River became one of the most heavily used logging rivers in the central United States (Dunn 1979). Early in this century, an 18-m-high hydroelectric dam was built on the mainstem at St. Croix Falls, Wisconsin, which in Minnesota is known as Taylors Falls (Fig. 1), and numerous smaller hydroelectric dams (most of which have been removed) were constructed along many of the tributaries. In 1880, the U.S. Army

Corps of Engineers began dredging a 1-m-deep navigation channel through the downstream 40 km of the mainstem. A wingdam was constructed in 1910 near St. Mary's Point, and by 1938 the navigation channel had been deepened to its present depth of 3 m. Commercial barge traffic peaked at 120 tows/year in the early 1970's (Waters 1977). Today, barge traffic has nearly ceased, largely because of the Allen King Power Plant near Stillwater, Minnesota, switching to rail for coal transport and to the closing of a nearby fertilizer plant, but is virtually non-existent today. Several hydroelectric dams still produce a few megawatts of electricity during peak demands, but the St. Croix River today is primarily a recreational resource.

In 1968, 165 km of the St. Croix River upstream of the Taylors Falls Dam and 157 km of the Namekagon River were (combined) one of eight streams or reaches in the United States to be approved as part of the National Wild and Scenic Rivers System. In 1972, the lower 87 km of the St. Croix River were added to this system. The so-called riverway corridor averages about 0.4 km of land on either side of the stream channel. The National Park Service's management plan for the riverway corridor is restricted by the National Wild and Scenic Rivers Act to acquiring no more than 25 ha/km by fee (U.S. National Parks Service 1976a, 1976b). At present, there are 37,500 ha along 409 km of the St. Croix and Namekagon rivers that are designated as the St. Croix National Scenic Riverway, and 86% of this land is under federal, state, or local zoning control (Victoria Grant, U.S. National Park Service, St. Croix Falls, Wisconsin, personal communication). The reach upstream of the impounded waters at Taylors Falls to the headwaters of the St. Croix and Namekagon rivers and the reach extending 16 km downstream from the Taylors Falls Dam are designated "scenic," while the impounded waters and remainder of the lower St. Croix River are designated "recreational." The National Park Service is the federal management agency for the Wild and Scenic Rivers System and, therefore, makes rules and policy for the entire St. Croix–Namekagon river corridor. According to Waters (1977), the St. Croix River is "... the outstanding recreational river resource of the Upper Midwest."

The objective of this paper is to provide (1) a summary of the geologic formation of the river valley and its drainage basin; (2) a brief analysis of recent land-use and vegetative-cover patterns; (3) a summary of surface water quality in the basin and its relation to geologic features, land-use, and vegetative-cover patterns; (4) a listing of aquatic biota within the basin; and (5) an evaluation of the status of the fish community. Issues of concern are identified, and recommendations for future planning, management, and protection of St. Croix River resources are presented.

Characterization of the River and its Basin

Physiography

The St. Croix River is a sixth-order stream that drains a 20,018-km^2 area (L. G. Perry, Wisconsin Department of Natural Resources (WDNR), Madison, personal communication) in east-central Minnesota and northwestern Wisconsin (Fig. 1). The river begins at the outlet of Upper St. Croix Lake (346 ha) near Solon Springs, Wisconsin, and flows 276 km southwest and then south to its confluence with the Mississippi River at Prescott, Wisconsin (Fago 1986). It forms the border between Wisconsin and Minnesota for the last 210 km. One 4-m-high dam at Gordon, Wisconsin, impounds 774 ha of water in the mainstem of the St. Croix River, and another 18-m-high hydroelectric dam, which spans the river between St. Croix Falls, Wisconsin, and Taylors Falls, Minnesota, impounds 314 ha (Fig. 1). An old logging dam (Never's Dam, formerly located about 18 km upstream from Taylors Falls) was removed in 1955 (Daniels 1990). The rest of the river is free-flowing, although the final 26.4 km of the mainstem is a 1,889-ha natural lake (Lake St. Croix).

The average gradient of the St. Croix is 0.47 m/km. The 129-km reach from the headwaters down to the bridge on Highway 70 near Grantsburg, Wisconsin, averages 0.56 m/km and is steepest (1.05 m/km) in the Kettle River Rapids, a 13-km reach near the mouth of the Kettle River (Fig. 1). From Grantsburg to Taylors Falls, the river gently meanders through the low relief of the Anoka Sand Plain, and the average gradient falls to 0.15 m/km. The river in the vicinity of Taylors Falls used to include a 10-km reach of steep rapids (1.81 m/km) that were known as St. Croix Falls (Underhill 1955); however,these rapids have been inundated since 1909 by the Taylors Falls Dam. From the dam to the beginning of Lake St. Croix, near Stillwater, Minnesota, the gradient is reduced to 0.09 m/km.

St. Croix River Basin

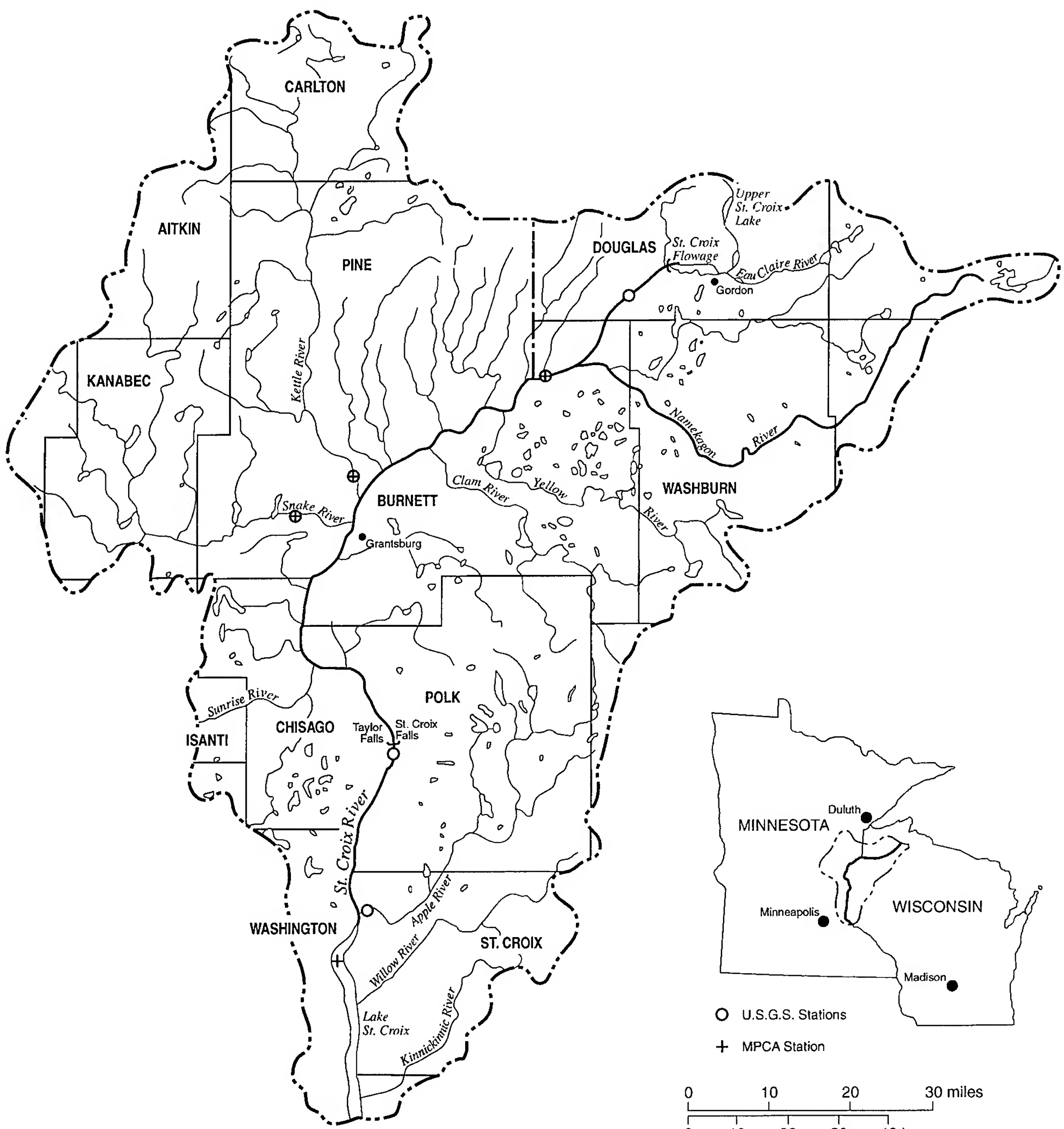

Fig. 1. Map of the St. Croix River basin with the U.S. Geological Survey and Minnesota Pollution Control Agency's monitoring stations (modified from Graczyk 1986).

Contrary to Green's assertion (Green 1935), the St. Croix Falls, which was only a series of rapids, was not a physical barrier to fish and mussel movements within the St. Croix River (Upham 1900; Underhill 1957). However, the St. Croix Falls Dam, constructed 84 years ago, has been a barrier, and it will be used in this paper to delineate the upper from the lower St. Croix basin. There are an additional 134 dams on tributary streams in the basin, but their effects on faunal movements have not been assessed.

Within the entire basin there are 1,770 tributary streams to the St. Croix River (9,004 km total length), of which 1,077 are in Minnesota. Ninety-eight of these streams drain directly into the St. Croix mainstem, but most drain into the St. Croix's six major tributaries (Snake, Kettle, Namekagon, Apple, Clam, Yellow rivers). Minnesota has a greater number of streams, but the total length of streams in each state is about the same (Table 1). All of the major tributaries, except the Apple River, drain into the St. Croix River upstream of the Taylors Falls Dam. The Sunrise River, the major tributary in Chisago County, Minnesota, also enters the mainstem upstream of the dam. The Apple River and two smaller Wisconsin tributaries, the Willow and Kinnickinnick rivers, enter downstream of the dam.

On the St. Croix River, or connected directly to a tributary stream, are 628 lakes (≥ 0.4 ha surface area) that have a total surface area of 41,012 ha. An additional 1,725 lakes that do not have a surface water connection to the St. Croix River occur within the basin (Table 2). The Wisconsin portion of the St. Croix River basin contains 82% of the open lakes and 78% of the closed lakes in the basin. These lakes account for 67% of the total lake area of the basin.

The St. Croix River flows through three of the ecoregions described by Omernik and Gallant (1988). Nearly 58% of the basin is in the Northern Lakes and Forests ecoregion, a region characterized by conifer and hardwood stands with extensive areas of wetlands and lakes; 39% is in the Central Hardwoods Forests ecoregion, which is characterized by northern deciduous hardwood species; and 3% is in the Western Corn Belt.

Geology

The bedrock of the upper St. Croix basin includes a large central area of late Precambrian basalt, flanked on the west by late Precambrian granite and sandstones, and on the east and south by Cambrian sandstones and shale (Helgesen et al. 1973; Lindholm et al. 1974a; Mudrey et al. 1982). Except for a finger of Precambrian basalt that extends southward to Taylors Falls, Minnesota, all of the bedrock of the lower St. Croix basin is Cambrian and Ordovician sandstones and dolomite (Young and Hindall 1973; Lindholm et al. 1974b; Morey 1976; Mudrey et al. 1982). Nearly all of the bedrock is overlain with glacial till and outwash, which is more than 70 m thick in many of the bedrock valleys. The lithologic composition of glacial deposits defies geographic summary, but in general heavy metal content (especially iron and manganese) tends to decrease and carbonate content tends to increase from north to south.

Along the river valley itself, the bedrock types mentioned above have been deeply eroded and subsequently fractured, leaving behind spectacular facades that contribute greatly to the scenic value of the river. The rather wide and deep valley, strikingly noticeable in the lower St. Croix, was excavated by torrential flows of glacial meltwater that continued for 1,400–1,500 years (Clayton 1983; Hobbs 1983; Farrand and Drexler 1985). At Taylor's Falls, Minnesota, where the water encountered resistant basaltic bedrock, the steeped-sided St. Croix Dalles was formed.

At the river's confluence with the Mississippi River, a 0.8-km spur of land from the Minnesota side narrows the river channel to 0.2 km. The wide floodplain established by Glacial River St. Croix permits maintenance of the spur by allowing the water to spread out behind it over the inner floodplain, thus forming Lake St. Croix (Schwartz and Thiel 1954). The lake level also has been influenced since 1935 by the operation of Mississippi River Lock and Dam 3 near Redwing, Minnesota, which backs up Mississippi River water (0.2 m at the normal high water mark) into Lake St. Croix (K. Willis, U.S. Army Corps of Engineers, St. Paul, Minnesota, personal communication).

Hydrology and Streamflow

We used discharge data collected by the U. S. Geological Survey at six gaging stations to characterize streamflow within the basin (Table 3). Hydrographs for the six gaging stations revealed fairly stable annual discharges over periods that varied from 23 to 88 years (Figs. 2 and 3). The Namekagon River and the Wisconsin portion of the St. Croix River showed less fluctuation around the average

Table 1. Inventory of tributary streams and geographic–geopolitical subbasins of the St. Croix River basin.[a]

Subbasins	Number tributaries	Total length (km)	Drainage area (km)^2
Snake River	327	1,476	2,618
Kettle River	297	1,432	2,699
Other Pine Co. tributaries	41		1,448
All other tributaries	412	1,884[b]	2,424
Minnesota total	1,077	4,792	9,189
Namekagon River	212	1,223	2,668
Apple River	71	479	1,502
Clam River	71	476	989
Yellow River	55	286	969
All other tributaries	284	1,748	470
Wisconsin total	694	4,212	10,829
Total (Wisconsin and Minnesota)	1,770	9,004	20,018

[a] Data were obtained from Minnesota Department of Natural Resources Stream Inventory Data Retrieval System (SIDRS), Wisconsin Department of Natural Resources Master Waterbody File, and Henrich and Daniel 1983.
[b] Includes the 41 tributaries of "Other Pine Co."

Table 2. Inventory of St. Croix River basin lakes (≥ 0.04 ha) by subbasins.[a]

	Number of lakes			Surface area of lakes (ha)		
Subbasins	Open lakes[b]	Closed lakes[c]	Total	Open lakes[b]	Closed lakes[c]	Total
Snake River	16	16	32	2,322	264	2,586
Kettle River	61	57	118	2,757	1,409	4,166
Other Pine Co. tributaries	7	23	30	92	280	372
All other tributaries	30	178	208	4,632	7,059	11,691
Minnesota total	114	274	388	9,803	9,011	18,814
Namekagon River	155			8,969		
Apple River	79			5,796		
Clam River	58			2,057		
Yellow River	67			4,399		
All other tributaries	147			6,665		
Wisconsin total	506	831	1,337	27,886	16,073	43,959
Mainstem	4			3,325		
Total (Minnesota and Wisconsin)	628	1,725	2,356	41,012	25,084	66,096

[a] Data were obtained from Minnesota Department of Natural Resources Lakes Data Base and Wisconsin Department of Natural Resources Master Waterbody File.
[b] Open = lake has tributary connection to St. Croix River.
[c] Closed = lake has no tributary connection to St. Croix River.

Table 3. Summary of streamflow characteristics for the St. Croix River basin.

Stream characteristics	Namekagon River near Trego, Wisconsin	St. Croix River near Danbury Wisconsin	Kettle River below Sandstone Minnesota	Snake River near Pine City, Minnesota	St. Croix River at St. Croix Falls, Wisconsin	Apple River near Sommerset, Wisconsin
Period of record	1927–70 1987–90	1914–81 1984–90	1967–90	1951–81	1902–90	1914–70 1986–90
Drainage area (km^2)	1,260	4,090	2,240	2,480	16,160	1,500
Average annual mean discharge (cms)	13.0	36.5	19.8	16.5	120.0	8.5
Catchment's annual mean discharge (cms/km^2)	0.01	0.009	0.009	0.007	0.007	0.006
Runoff (mm)	328	284	282	213	238	181
Overland runoff (mm)	44	44	93	59	81	52
Groundwater flow (mm)	284	240	189	154	157	129
Percent of total streamflow from groundwater	86	85	67	72	66	71

mean discharge than did the Kettle, Snake, and Apple rivers. Because the Namekagon and upper St. Croix rivers drain catchments with highly permeable stratified sand and gravel soils, spate events were minimized. During periods of low precipitation, streamflow in these reaches was stabilized by high groundwater contributions (Table 3). These two factors attenuated annual differences in precipitation and resulted in more stable annual mean streamflow.

Using the methods of Hirsch and Slack (1984), we carried out a time-trend analysis on each station's data set to determine if a trend in discharge existed. The analyses revealed a statistically significant increasing trend in discharge at the St. Croix River stations near Danbury, Wisconsin, and at St. Croix Falls ($P < 0.10$). We are unable to account for this trend. An increase in annual precipitation would be the most likely cause of the trend, but a similar trend analysis of long-term precipitation records from the Spooner Experimental Farm in Spooner, Wisconsin, did not reveal a statistically significant increase in precipitation. The amount of vegetative land-cover has changed little in the last 30 years, and wetland losses have been minimal.

Land-cover

Presettlement land-cover within the St. Croix River basin included several vegetation types within three major North American biomes: northern coniferous forest, eastern deciduous forest, and tallgrass prairie (Küchler 1964; Wendt and Coffin 1988). The northern two-thirds of the upper basin (including the headwaters, Namekagon, Yellow, Clam, Pine County tributaries, Kettle, and much of the Snake subbasins) was dominated by a mosaic of Great Lakes pine forest (white pine, red pine, paper birch, aspen), boreal hardwood–conifer forest (aspen, birch, balsam fir, white spruce, white cedar), and a variety of peatlands (e.g., black spruce–

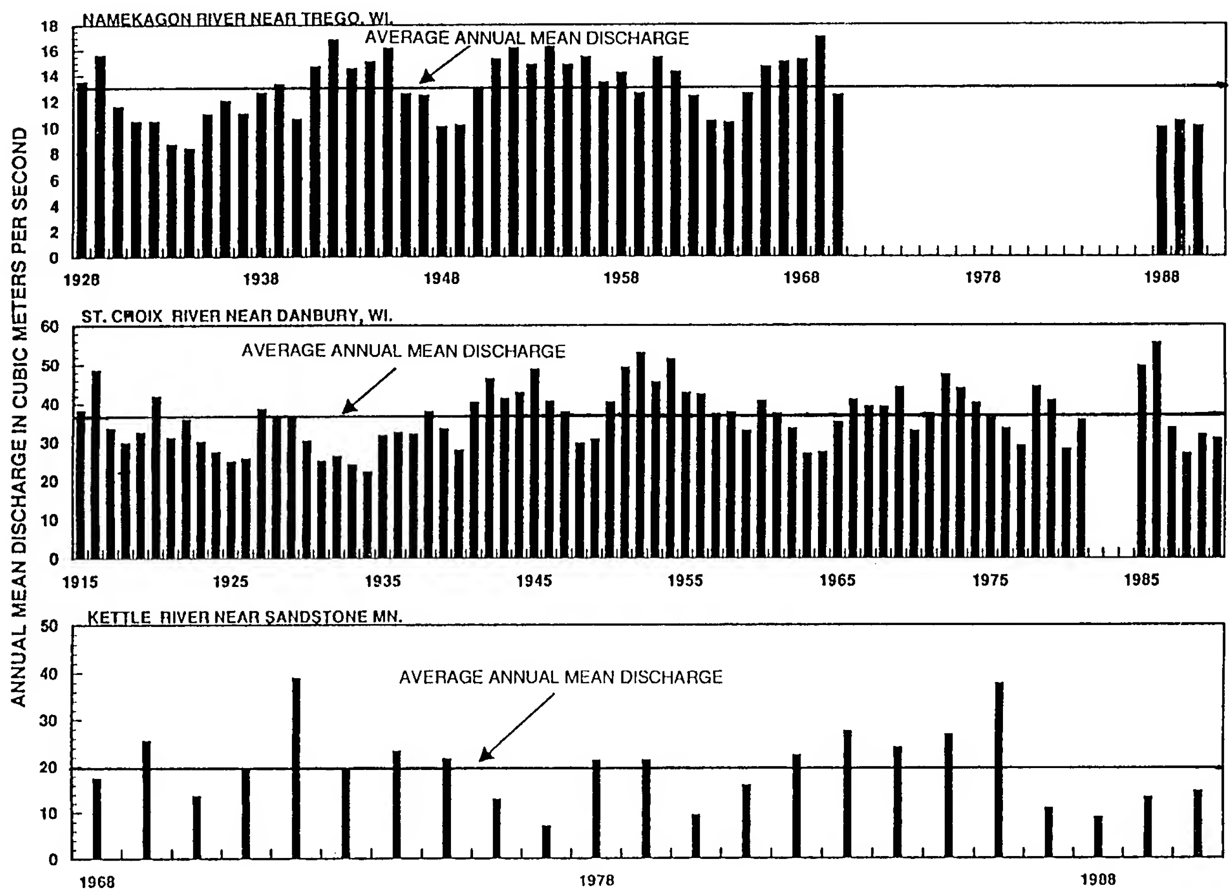

Fig. 2. Average mean discharge and annual mean discharge for the period of record at the Namekagon, St. Croix, and Kettle rivers (Graczyk 1986).

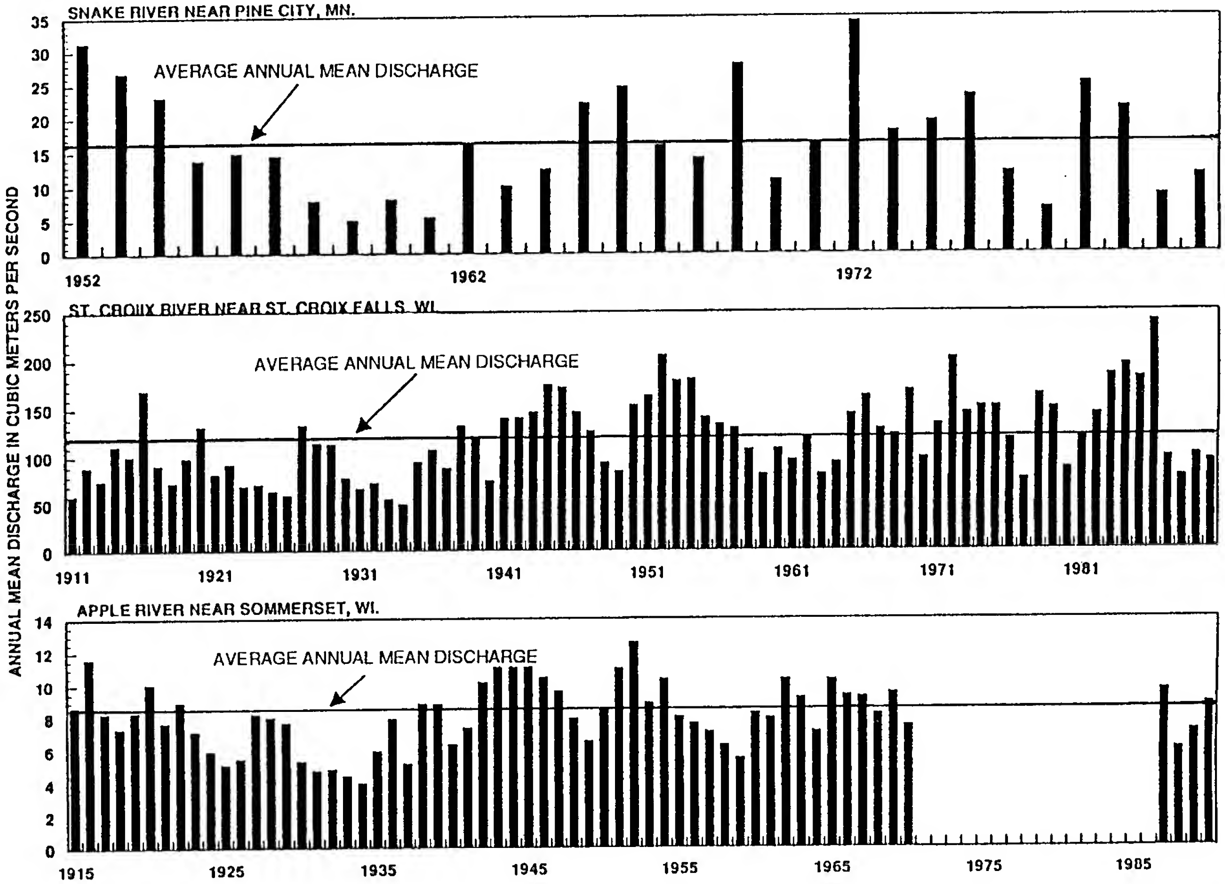

Fig. 3. Average mean discharge and annual mean discharge for the period of record at the Snake, St. Croix, and Apple rivers (Graczyk 1986).

tamarack bogs, open sphagnum–sedge bogs, white cedar bogs, ash–alder swamps). The southern third of the upper basin (including the Wood, Trade, and some of the southern Snake subbasins) was dominated by northern hardwood forest (sugar maple, basswood, and yellow birch with some white pine) and oak woodland (bur oak, pin oak, aspen, hazel). Lower basin land was covered primarily with oak woodland, but eastern Washington County, Minnesota, and large portions of Polk and St. Croix counties in Wisconsin (Fig. 1), were covered by upland prairies of bluestems, indian grass, needle grass, grama grasses, and a variety of composite (Asteraceae) forbes.

Land Use

Before 1837, the land of the St. Croix basin was used only for hunting and trapping by Native Americans, French voyagers, and British woodsmen. Soon after the treaty of 1837, in which the United States obtained the St. Croix Delta area from the Dakota and Ojibwe, lumbermen began harvesting the extensive stands of white pine and other timber species. From 1839 through 1914, more than 15 billion board-feet of timber left the St. Croix River basin by raft and rail. By the time the last of the St. Croix's 133 saw mills had closed, agriculture had become the dominant industry of the basin (Waters 1977; Dunn 1979). The soggy soils of the lowlands and the shallow, sandy upland soils produced poorly, and during the Great Depression, farm after farm succumbed to tax forfeiture. As late as 1963, nearly 20% of the land in the Minnesota portion of the St. Croix River basin was still in tax forfeiture (Huber 1966).

It is difficult to paint an up-to-date picture of land use throughout the basin because state Geo-

graphic Information System (GIS) data available in 1992 were procured in 1968–69 in Minnesota and 1974–77 in Wisconsin. More recent data are available only on a county by county basis and, therefore, are not basin specific. To gain some perspective on the historical pattern of land use, we hypothesized that data for Carlton, Chisago, Kanabec, Pine, and Washington counties would typify the Minnesota portion of the entire basin and that data for Burnett, Douglas, Polk, St. Croix, and Washburn counties would typify the Wisconsin portion. To test this hypothesis, we used two GIS data sets to calculate land-use percentages on a watershed basis and on a five-county basis for each state. The two types of calculations yielded percentages within 1 to 2 points of one another for each of six land-use categories (Fig. 4).

Under the assumption that such comparisons would be temporally stable, we analyzed data sets for the 10 counties from the 1959, 1969, 1978, and 1987 agricultural censuses (U.S. Bureau of the Census 1959a, 1959b, 1969a, 1969b, 1978a, 1978b, 1987a, 1987b) to try to establish patterns of agricultural land use in the basin. Over the 29-year period, total farm acreage declined almost 30%. Acreage for cropland increased almost 6%, but acreage used for pasture decreased nearly 50%. In 1987, only 29% of the total basin land area (70% of the total farm acreage) was being used for pasture and cultivation.

To investigate patterns of forest cover, we used state forest inventory statistics published by the U.S. Forest Service North Central Forest Experiment Station. The minimum area used by the U.S. Forest Service for classification was 0.4 ha, and areal statistics were reported to the nearest 40 ha. We used separate data for Minnesota and Wisconsin because the data were collected in widely disparate years—1956, 1968, and 1983 for Wisconsin and 1962, 1977, and 1990 for Minnesota (Stone and Thorne 1959; Thorne and Stone 1959; Stone 1966; Spencer and Thorne 1972; Jakes 1980; Raile 1985; Spencer et al. 1988; Miles and Chen 1992). The area of forestland in the basin has declined only slightly during the last 30–35 years and is near 50% at present. It is comprised mostly of second-growth aspen–birch, maple–basswood, lowland hardwood, and oak–hickory forests (Fig. 5). Much of this forest area is included in the 1 national forest, 10 state forests, 11 state parks, and 6 wildlife management areas that occur partly or wholly within the basin and is managed partly for wildlife enhancement and recreational purposes.

Based on the 1960's and 1970's GIS data, about 3% of the total basin was covered in permanently standing water, and another 7% was considered wetland with seasonally standing water. Anderson and Craig (1984) provided figures for presettlement wetlands that indicate 24–31% of the Minnesota portion of the basin contained wet mineral or peat soils indicative of wetland habitat. More than 80% of these wetlands are in the drainage of the Snake, Kettle, and other Pine County tributaries. The numbers are not available that give the details of wetland change following settlement, but Anderson and Craig's data indicate a loss of about 12% of the wetland acreage in the Minnesota subbasin, and it is not unreasonable to

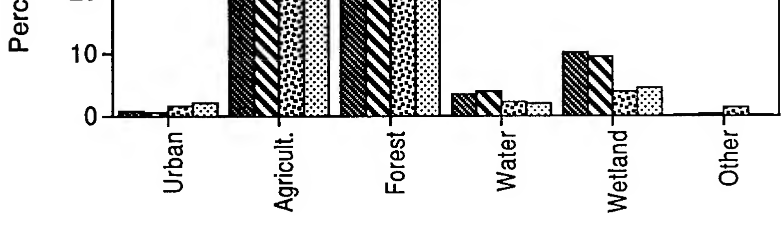

Fig. 4. Comparison of two methods for calculating percentage land use by area within the St. Croix River basin. The counties used as an estimate of state subbasins were Carlton, Chisago, Kanabec, Pine, and Washington in Minnesota, and Burnett, Douglas, Polk, St. Croix, and Washburn in Wisconsin. All data were taken from Wisconsin and Minnesota GIS data bases (see text), which were subjected to a land use by watershed sort and a land use by county sort.

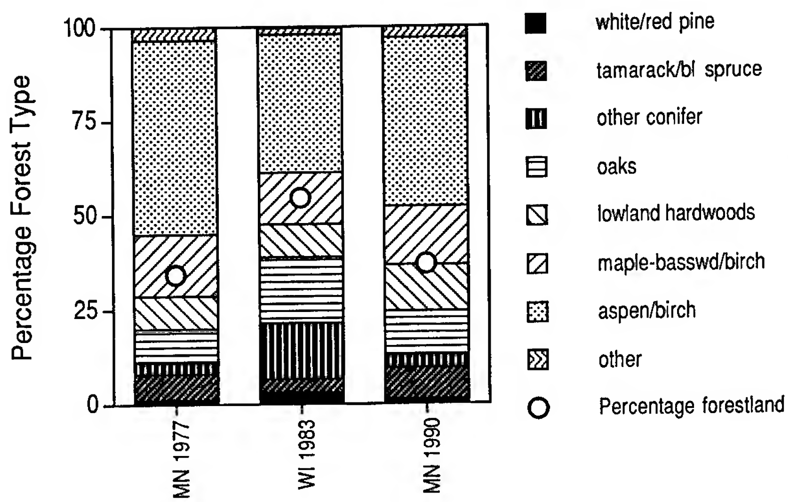

Fig. 5. Composition of forestland by forest type based on U.S. Forest Service inventory data reported for Carlton, Chisago, Kanabec, Pine, and Washington counties in Minnesota, and Burnett, Douglas, Polk, St. Croix, and Washburn counties in Wisconsin (Jakes 1980; Spencer et al. 1988; Miles and Chen 1992).

assume a similar loss in Wisconsin. Compared with other wetland losses in Minnesota, Wisconsin, and the rest of the nation (Dahl 1990; Dahl and Johnson 1991), the losses in the St.Croix River basin have been minuscule.

Despite the 230 municipalities in the basin, urban and commercial development account for only 1–2% of the land use. The majority of development is confined to the lower basin and is largely the result of the urban sprawl of Minneapolis and St. Paul, Minnesota. Although urban encroachment into the basin has been relatively small so far, the rate of metropolitan population growth (Fig. 6) suggests substantial residential, commercial, and transportation development will occur. Substantial increases in recreational use of forests and waters within the basin have already occurred. For example, from the early 1970's to the end of the 1980's, recreational boating on the lower St. Croix River increased from about 50,000 to nearly 120,000 boating trips per year (Fig. 7). With over 10 million people already living within a day's drive of the river, one of the major effects of the future will come from recreational uses.

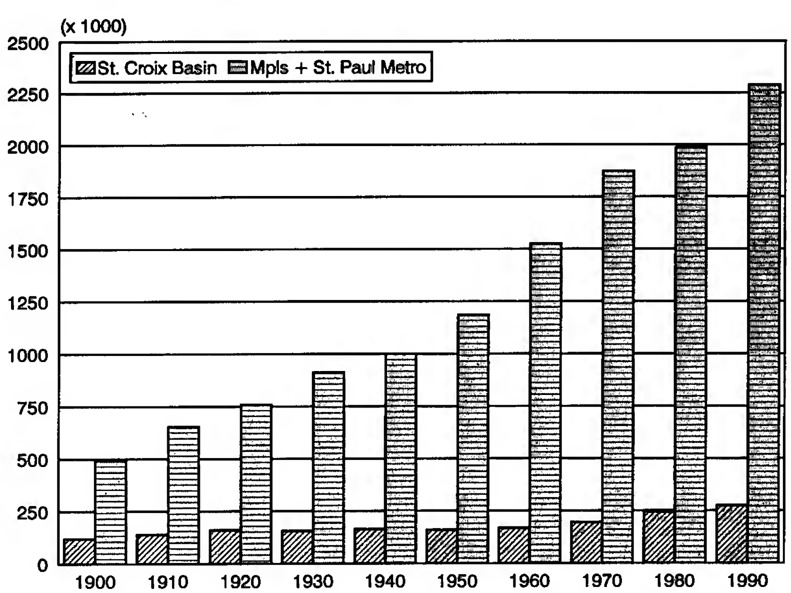

Fig. 6. Population in the St. Croix basin and Twin Cities Metro Area 1900–1990 Data from the U.S. Bureau of Census 1900–1990.

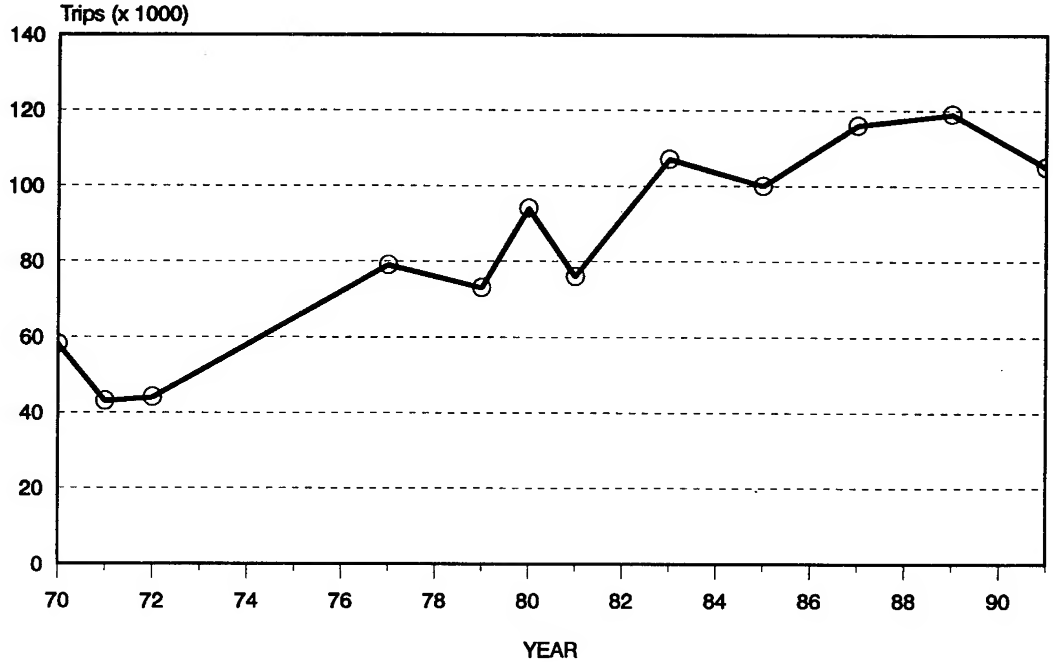

Fig. 7. Recreational boating growth in the lower St. Croix River (Minnesota-Wisconsin Boundary Area Commission, Hudson, Wisconsin, unpublished report).

Water Quality

From 1975 through 1983, the U.S. Geological Survey conducted a water quality study at 10 stations along the St. Croix River (Graczyk 1986). Nine of the stations were sampled semiannually, at high flow and low flow, for major inorganic constituents, nutrients, and suspended sediment. In addition, six of the stations were sampled annually for trace metals (Table 4; Fig. 1). The gaging station for the St. Croix River at St. Croix Falls, Wisconsin, became part of the National Stream Quality Accounting Network (NASQAN) and was sampled monthly in 1978–81, bimonthly in 1982, quarterly in 1983, and bimonthly in 1984–86.

The St. Croix River has calcium bicarbonate-type surface water, which reflects the composition of the groundwater discharge to the river. Average alkalinity (as $CaCO_3$) ranged from 36 mg/L at the Dairyland, Wisconsin, station to 110 mg/L at the

Table 4. Location, catchment size, and sampling regime of U.S. Geological Survey water quality monitoring stations in the St. Croix River basin, 1975–83.

Station number	River	Nearest city or town (Wisconsin)	Catchment (km^2)	Sampling regime
1	St. Croix	Dairyland	1,199	S
2	Namekagon	Hayward	438	S,T
3	Namekagon	Trego	1,264	S,T
4[b]	St. Croix	Danbury	4,092	S,T
5	Yellow	Danbury	969	S
6	Clam	Webster	935	S
7[b]	Kettle	Cloverdale	2,719	S
8[b]	Snake	Pine City	1,445	S,T
9	Apple	Sommerset	1,500	S,T
10	St. Croix	St. Croix Falls	16,162	B,T

[a] B = bimonthly water quality samples, S = semiannual water quality samples, T = annual trace metal samples (modified from Graczyk 1986).

[b] Also locations of Minnesota Pollution Control Agency long-term sampling stations.

Apple River near Sommerset, Wisconsin. Measurements of pH at all stations varied from 6.0 to 9.2; the highest mean (7.8) occurred at the Apple River, and the lowest mean (6.9) occurred at the St. Croix River at Dairyland, Wisconsin, and Kettle River near Cloverdale, Minnesota. Spring (February–April) and fall (October) dissolved oxygen measurements ranged from 8.6 to 14.0 mg/L, whereas summer (July–August) measurements ranged from 6.5 to 11.0 mg/L. Suspended sediment measurements throughout the basin were always less than 60 mg/L, mean values generally were less than 10 mg/L, and there was little discernable pattern in the measurements (Fig. 8). Measurements of total nitrogen and total phosphorus indicated that the upper third of the basin (upstream of the Yellow River) received less nutrient enrichment than the lower two-thirds (Figs. 9 and 10). Compared with other midwestern streams of comparable basin size, the St. Croix River has very low concentrations of suspended-sediment and total phosphorus (Table 5).

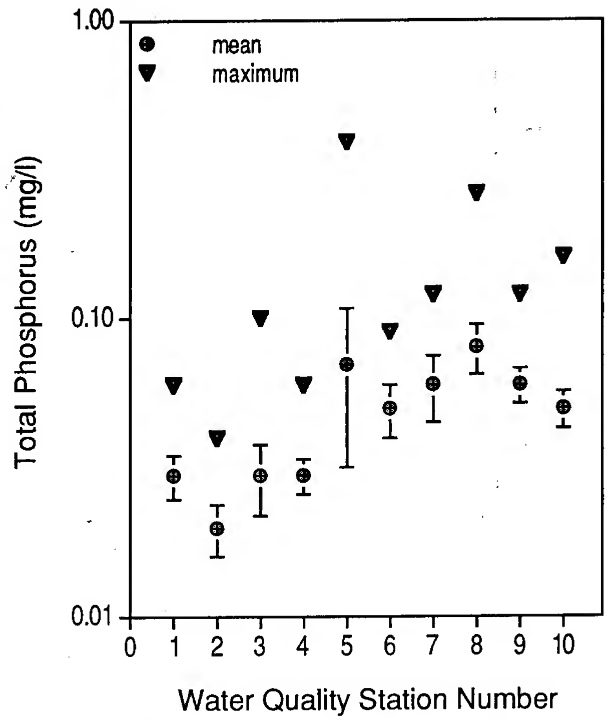

Fig. 9. Mean and maximum total phosphorus (milligrams/liter) concentrations measured at 10 U.S. Geological Survey water quality stations in the St. Croix River basin, 1975–83. Error bars are two standard errors. Station locations are listed in Table 4 (Graczyk 1986).

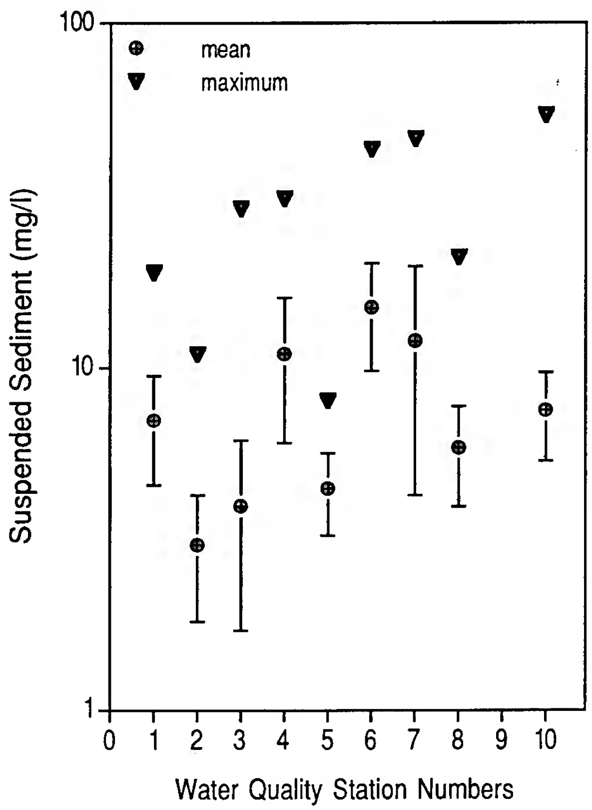

Fig. 8. Mean and maximum suspended sediment (milligrams/liter) concentrations measured at 10 U.S. Geological Survey water quality stations in the St. Croix River basin, 1975–83. Error bars are two standard errors. Station locations are listed in Table 4 (Graczyk 1986).

Streambank erosion, although not severe, has been reported along the Snake River (Linder 1990) and noted within the lower reach of the Sunrise River by one of the authors (J. Hatch). It is locally severe along sections of small feeder streams to the Snake River where cattle have free access to the water (R. Hugill, Minnesota Department of Natural Resources, personal communication). Nevertheless, the St. Croix River continues to exhibit one of the lowest suspended sediment loads in the Upper Midwest (Hatch 1982, 1985; Tornes 1986; Troelstrup and Perry 1989).

The trace metal analyses conducted as a part of the U.S. Geological Survey study showed that arsenic, cadmium, chromium, cobalt, copper, lead, mercury, selenium, and zinc occurred in low concentrations at all six stations sampled (Table 6). However, total recoverable iron and manganese concentrations exceeded recommended drinking water concentrations on at least one occasion at every station.

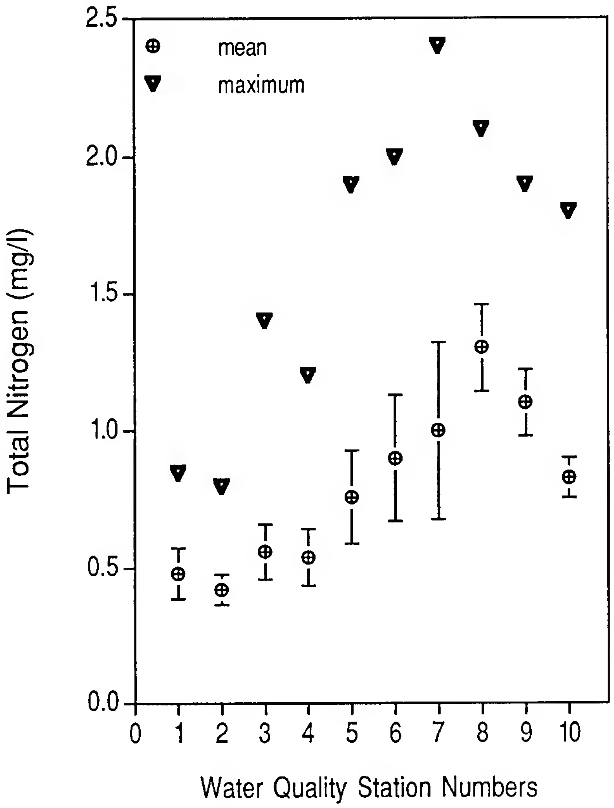

Fig. 10. Mean and maximum total nitrogen (milligrams/liter) concentrations measured at 10 U.S. Geological Survey water quality stations in the St. Croix River basin, 1975–83. Stations locations are listed in Table 4 (Graczyk 1986).

The mean measurement of total recoverable iron exceeded the recommended concentration of 300 µg/L at four stations, and the mean of total recoverable manganese exceeded the recommended concentration of 50 µg/L at five stations. Iron measurements were greatest at the St. Croix Falls stations (mean = 880 µg/L), and manganese measurements were highest at the Snake River station (mean = 130 µg/L; Graczyk 1986). These measurements reflect the mineral composition of glacial tills in the basin.

Another source of water quality information is the Minnesota Pollution Control Agency (MPCA). Since 1978, MPCA (1992) has identified no waters within the St. Croix River basin that exhibit "significant water quality violations." However, many lakes suffer from cultural eutrophication and heavy metals contamination (MPCA 1988, 1990, 1992). During the water years 1990–1991 (MPCA 1992), 14 stream reaches totaling 333 km (6.7% of the total) were identified as exhibiting minor to moderate pollution effects from nutrients, heavy metals, chlorine, and other toxic chemicals. Two-thirds of the kilometers affected were in the Sunrise and lower St. Croix rivers. Twenty-four percent of these waters were affected by municipal discharges, and 33% were affected by non-point sources. The major nonpoint source problems were associated with poor livestock management practices and surface runoff from urban areas and land disposal sites (MPCA 1992).

According to MPCA (1992), pesticide contamination of stream water and sediments is not a problem in the basin. In 1976, the U.S. Geological Survey conducted studies on residual pesticides at St. Croix Falls (Graczyk 1986). A water suspended-sediment mixture was analyzed for 18 residues, and no residues were detected. In 1981 near a commercial cranberry bog on the Namekagon River, another suspended sediment sample and a bottom sediment sample were analyzed for 27 residues. No residues were detected.

One very discouraging aspect associated with water quality sampling has been the results of fish flesh analyses for biologically magnifiable toxins, such as polychlorinated biphenyls (PCB) and methyl mercury. In the mainstem of the lower St. Croix River, PCB consumption advisories have been issued for northern pike, common carp, bigmouth buffalo, smallmouth buffalo, channel catfish, white bass, smallmouth bass, walleye, sauger, and freshwater drum (Minnesota Department of Health 1991). The level of contamination increased in a downstream direction. In contrast to PCB contamination, methyl mercury contamination is more of a problem in the upper St. Croix River. This problem may be the result of atmospheric deposition of mercury (Sorenson et al. 1989; Swain and Helwig 1989).

Fish

Distribution

Determination of the distribution of fishes within the basin was made by reviewing the collection records of the Wisconsin Department of Natural Resources, the James Ford Bell Museum of Natural History, and the personal collection records of J. C. Underhill. The following published and unpublished sources were also reviewed: Greene (1935), Eddy and Underhill (1974), Phillips et al. (1982), Becker (1983), Fago (1986, 1992),

Table 5. Summary of water quality constituents (milligrams/liter) for selected Upper Midwest National Stream Quality Accounting Network Stations.

Site	Water quality constituent	Drainage area (km^2)[a]	Sample size	Maximum	Minimum	Mean
St. Croix River at	Suspended sediment	6,240	100	54	1.0	8.3
St. Croix Falls, Wisconsin	Total phosphorus		107	0.19	0.01	0.045
Cedar River at	Suspended sediment	12,261	44	494	3.0	64
Cedar Falls, Iowa	Total phosphorus		92	0.76	0.01	0.22
Iowa River at	Suspended sediment	32,372	82	1520	4.0	230
Wapello, Iowa	Total phosphorus		97	1.0	0.07	0.32
Rock River near	Suspended sediment	24,732	89	678	12	120
Justin, Illinois	Total phosphorus		225	1.9	0.03	0.32
Illinois River at	Suspended sediment	21,391	145	3870	5.0	124
Marseilles, Illinois	Total phosphorus		282	1.4	0.14	0.46
Spoon River at	Suspended sediment	4,237	23	4240	28	569
Seville, Illinois	Total phosphorus		107	1.8	0.02	0.27
Minnesota River near	Suspended sediment	41,958	74	615	22	156
Jordan, Minnesota	Total phosphorus		162	0.86	0.07	0.24
St. Louis River at	Suspended sediment	8,884	92	100	2.0	15
Scanlon, Minnesota	Total phosphorus		127	0.50	0.01	0.51
Bad River near	Suspended sediment	1,546	187	1920	0.0	60.8
Odanah, Wisconsin	Total phosphorus		64	0.16	0.01	0.04
Milwaukee River near	Suspended sediment	1,803	191	282	1.0	32.8
Milwaukee, Wisconsin	Total phosphorus		176	0.62	0.03	0.175

[a] At sampling station.

Hatch (1986), Cochran (1987), Underhill (1989), MDNR (unpublished reports), Simon (unpublished report), WDNR (unpublished reports). Records were accepted if an extant specimen could be found and verified, or if a competent ichthyologist had made or verified the identification of the specimen.

One hundred ten species of fish representing 24 families have been identified from the St. Croix River basin (Table 7). The common and scientific names used in this report follow names established by the American Fisheries Society's Committee on Names of Fishes (Robins 1991). Six species (common carp, blue catfish, muskellunge, rainbow trout, brown trout, and lake trout) have been introduced. The recent occurrence of blue catfish in Lake St. Croix is from a 1977 stocking by MDNR. Although individuals from that stocking may still be present, there are no verifiable accounts of adults or young from the lower St. Croix River. Whether the blue catfish historically was native to the St. Croix River basin is debatable. Cox (1897) and Surber (1920) referred to specimens that could have been blue catfish, but verification cannot be attained from their descriptions, and there are no known extant specimens. Lake trout were stocked in Grindstone Lake in the Kettle River basin over 25 years ago, but there is no evidence of range expansion within the St. Croix River basin. Seven other native species (shovelnose sturgeon, goldeye, skipjack herring, pallid shiner, river shiner, weed shiner, and mud darter) have not been identified from the basin since 1974. Presence of the shovelnose sturgeon was based solely on a pre-World War II record by S. Eddy (Eddy and Underhill 1974) at Taylors Falls. Presence of the goldeye was based on three records from Lake St. Croix in 1942, 1967, and 1968 (Eddy and Underhill 1974). There have been unverified records of goldeye being taken in Lake St. Croix in 1967, 1971, 1973, 1975, 1977, and 1979 (J. Stewart and B. Gilbertson, MDNR, St. Paul Minnesota, unpublished report). The skipjack herring, once thought to be extirpated from the Mississippi River basin upstream of the Keokuk Dam because of blockage of its upstream migration at this dam, was collected in the 1980's at several locations on the Mississippi River in Wisconsin. It may also be expanding its range back into the lower St. Croix River. The presence of the pallid shiner is based on only two records (1900 and 1926) in the St. Croix River at stations 0.5 and 103.5 km from its mouth (Greene 1935). The river shiner was collected at three stations in the lower St. Croix River in the early 1900's; it was last collected by J. C. Underhill in 1968 at a single station near Taylors

Table 6. Maximum, minimum, mean, standard deviation, and number of samples of trace metals for the St. Croix River at St. Croix Falls (modified from Graczyk 1986).

Trace metals	Total arsenic	Total recoverable									
		Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Selenium	Zinc
Maximum	3.0	3	20	4	24	4,000	63	160	0.6	1	380
Minimum	<1.0	<1	<20	<2	<2	200	<2	20	<0.1	<1	<10
Mean	1.0	1.0	9	1.0	4.0	880	10	80	0.20		30
Standard deviation	0.50	0.80	6.0	1.0	5.0	730	12	30	0.20		70
Number of samples	30.0	30	30	30	30	30	30	30	30	29	29

Table 7. List of common and scientific names of all fish species found in the

Common name	Scientific name	St. Croix basin	L. St. Croix basin	U. St. Croix basin	Kinnickinnic basin	Willow basin	Apple basin
Chestnut lamprey	*Ichthyomyzon castaneus*	X	X	X			
Northern brook lamprey	*I. fossor*	X		X			
Southern brook lamprey	*I. gagei*	X		X			
Silver lamprey	*I. unicuspis*	X	X	X			
American brook lamprey	*Lampetra appendix*	X	X		X		
Lake sturgeon	*Acipenser fulvescens*	X	X	X			
Shovelnose sturgeon	*Scaphirhynchus platorynchus*	P	P				
Paddlefish	*Polyodon spathula*	X	X				
Longnose gar	*Lepisosteus osseus*	X	X				
Shortnose gar[a]	*L. platostomus*	X	X				
Bowfin	*Amia calva*	X	X	X			
Goldeye	*Hiodon alosoides*	P	P				
Mooneye	*H. tergisus*	X	X				
American eel	*Anguilla rostrata*	X	X				
Skipjack herring	*Alosa chrysochloris*	P	P				
Gizzard shad	*Dorosoma cepedianum*	X	X			X	
Central stoneroller	*Campostoma anomalum*	X	X	X	X	X	X
Largescale stoneroller	*C. oligolepis*	X		X			
Spotfin shiner	*Cyprinella spiloptera*	X	X	X			X
Common carp	*Cyprinus carpio*	I	I	I	I	I	I
Brassy minnow	*Hybognathus hankinsoni*	X	X	X		X	X
Common Shiner	*Luxilus cornutus*	X	X	X	X	X	X
Speckled chub	*Macrhybopsis aestivalis*	X	X				
Silver chub	*M. storeriana*	X	X				
Pearl dace	*Margariscus margarita*	X	X	X		X	X
Hornyhead chub	*Nocomis biguttatus*	X	X	X		X	X
Golden shiner	*Notemigonus crysoleucas*	X	X	X		X	X
Pallid shiner	*Notropis amnis*	P	P	P			
Pugnose shiner	*N. anogenus*	X		X			
Emerald shiner	*N. atherinoides*	X	X		X		X
River shiner	*N. blennius*	P	P				
Bigmouth shiner	*N. dorsalis*	X	X	X	X	X	X
Blackchin shiner	*N. heterodon*	X	X	X			X
Blacknose shiner	*N. heterolepis*	X	X	X			X
Spottail shiner	*N. hudsonius*	X	X	X	X		X
Sand shiner	*N. stramineus*	X	X	X			X
Weed shiner	*N. texanus*	P	P	P			P
Mimic shiner	*N. volucellus*	X	X	X	X		X
Pugnose minnow	*Opsopoeodus emiliae*	X	X				
Northern redbelly dace	*Phoxinus eos*	X	X	X		X	X
Finescale dace	*P. neogaeus*	X	X	X			X
Bluntnose minnow	*Pimephales notatus*	X	X	X	X	X	X
Fathead minnow	*P. promelas*	X	X	X	X	X	X
Blacknose dace	*Rhinichthys atratulus*	X	X	X	X	X	X
Longnose dace	*R. cataractae*	X	X	X	X	X	X
Creek chub	*Semotilus atromaculatus*	X	X	X	X	X	X
Quillback	*Carpiodes cyprinus*	X	X	X			X
Highfin carpsucker[a]	*C. velifer*	X	X				
White sucker	*Catostomus commersoni*	X	X	X	X	X	X
Blue sucker[a]	*Cycleptus elongatus*	X	X	X			
Northern hog sucker	*Hypentelium nigricans*	X	X	X			X
Smallmouth buffalo[a]	*Ictiobus bubalus*	X	X				
Bigmouth buffalo[a]	*I. cyprinellus*	X	X				
Spotted sucker	*Minytrema melanops*	X	X				
Silver redhorse	*Moxostoma anisurum*	X	X	X	X		
River redhorse	*M. carinatum*	X	X	X			X
Golden redhorse	*M. erythrurum*	X	X	X			X
Shorthead redhorse	*M. macrolepidotum*	X	X	X	X	X	X
Greater redhorse[a]	*M. valenciennesi*	X	X	X			
Black bullhead	*Ameiurus melas*	X	X	X	X	X	X

St. Croix River basin and listed by its major subbasins, 1889–1990.

L. St. Croix all tribs	L. St. Croix R. (only)	Trade basin	Chisago Co. basin	Wood basin	Snake basin	Kettle basin	Pine Co. other tribs	Clam basin	Yellow basin	Namekagon basin	U. St. Croix all tribs	U. St. Croix R.(only)
	X		X	X	X	X	P	X	X	X	X	X
								X		X	X	
				X			X			X	X	
X	X		X			P						X
X												
	X				P	X		X			X	X
	P											
	X											
	X											
	X											
	X	X		X	X			X	X	X	X	X
	P											
	X											
	X											
	P											
X	X											
X		X	X		P					X	X	X
					X				X	X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X
I	I	I	I	I	I			I	I	I	I	I
X		X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
	X											
	X											
X			P		X	X	X	X	X	X	X	X
X		X	X	X	X	X	X	X	X	X	X	X
X	X	X	P	X	X	X		X	X	X	X	X
	P											P
								X	X	X	X	P
X	X											
	P											
X	P		X	X	P	X	X	X		X	X	X
X			P					X	X	X	X	X
X			X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X			X	X	X	X
X	X		X		X	X				X	X	X
	P											P
X	X		X		X	X	X		X	X	X	X
X	X											
X			X	X	X	X	X	X	X	X	X	X
X					X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
X		X	X	X	X		X	X	X	X	X	X
X	P	X	X	X	X	X	X	X	X	X	X	X
X		X	X	X	X	X	X	X	X	X	X	X
X	X				P	X						X
	X											
X	X	X	X	X	X	X	X	X	X	X	X	X
	X											X
X	X	X	X	X	X	X	X	X	X	X	X	X
	X											
	X											
	X											
X	X	X		X	X	X		X	X	X	X	X
X	X					X			X		X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X		X	X	X	X	X
	X								X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X

Table 7. *Continued.*

Common name	Scientific name	St. Croix basin	L. St. Croix basin	U. St. Croix basin	Kinnickinnic basin	Willow basin	Apple basin
Yellow bullhead	*A. natalis*	X	X	X		X	X
Brown bullhead	*A. nebulosus*	X	X	X	X	X	X
Blue catfish[a]	*Ictalurus furcatus*	I[b]	I[b]				
Channel catfish	*I. punctatus*	X	X	X			
Stonecat	*Noturus flavus*	X	P	X			
Tadpole madtom	*N. gyrinus*	X	X	X			X
Flathead catfish	*Pylodictis olivaris*	X	X	X			
Northern pike	*Esox lucius*	X	X	X		X	X
Muskellunge	*E. masquinongy*	I	I	I			I
Central mudminnow	*Umbra limi*	X	X	X	X	X	X
Cisco or lake herring	*Coregonus artedi*	X		X			
Rainbow trout	*Oncorhynchus mykiss*	I	I	I		I	
Brown trout	*Salmo trutta*	I	I	I	I	I	I
Brook trout	*Salvelinus fontinalis*	X	X	X	X	X	X
Lake trout	*S. namaycush*	I		I			
Trout-perch	*Percopsis omiscomaycus*	X	X	X			X
Burbot	*Lota lota*	X	X	X	X		
Banded killifish	*Fundulus diaphanus*	X	X	X			X
Brook silverside	*Labidesthes sicculus*	X	X	X			
Brook stickleback	*Culaea inconstans*	X	X	X	X	X	X
Mottled sculpin	*Cottus bairdi*	X	X	X	X	X	X
Slimy sculpin	*C. cognatus*	X	X	X	X		
White bass	*Morone chrysops*	X	X	P			X
Rock bass	*Ambloplites rupestris*	X	X	X		X	X
Green sunfish	*Lepomis cyanellus*	X	X	X		X	X
Pumpkinseed	*L. gibbosus*	X	X	X		X	X
Warmouth	*L. gulosus*	X	X				X
Bluegill	*L. macrochirus*	X	X	X		X	X
Longear sunfish[a]	*L. megalotis*	X		X			
Smallmouth bass	*Micropterus dolomieu*	X	X	X	X	X	X
Largemouth bass	*M. salmoides*	X	X	X		X	X
White crappie	*Pomoxis annularis*	X	X	X			
Black crappie	*P. nigromaculatus*	X	X	X		X	X
Crystal darter[a]	*Ammocrypta asprella*	X	X				
Western sand darter	*A. clara*	X	X				
Mud darter	*Etheostoma asprigene*	P	P				
Rainbow darter	*E. caeruleum*	X	X			X	X
Iowa darter	*E. exile*	X	X	X		X	X
Fantail darter	*E. flabellare*	X	X		X	X	
Least darter	*E. microperca*	X	X	X			X
Johnny darter	*E. nigrum*	X	X	X	X	X	X
Yellow perch	*Perca flavescens*	X	X	X		X	X
Logperch	*Percina caprodes*	X	X	X		X	
Gilt darter	*P. evides*	X	X	X			X
Blackside darter	*P. maculata*	X	X	X			
Slenderhead darter	*P. phoxocephala*	X	X	X		X	
River darter	*P. shumardi*	X	X				X
Sauger	*Stizostedion canadense*	X	X	P			
Walleye	*S. vitreum*	X	X	X			X
Freshwater drum	*Aplodinotus grunniens*	X	X	X			X
TOTAL	Total species	110	103	83	28	41	60
X or I = POST 1974		103	95	79	28	41	59
I = INTRODUCED		6	5	5	2	3	3
P = PRE 1975 ONLY		7	8	4	0	0	1

[a] Few or no specimens exist in subbasins or entire basin. Voucher specimens are requested.

[b] 1889 record exists without a specimen.

L. St. Croix all tribs	L. St. Croix R. (only)	Trade basin	Chisago Co. basin	Wood basin	Snake basin	Kettle basin	Pine Co. other tribs	Clam basin	Yellow basin	Namekagon basin	U. St. Croix all tribs	U. St. Croix R.(only)
X	P	X		X	X	X		X	X	X	X	X
X	P	X	X	X	X	X	X	X	X	X	X	X
	I[b]											
	X				X	X		X			X	X
	P		X	X	X	X	X	X	X	X	X	
	P	X	P	X	X	X	X	X	X	X	X	X
	X											X
X	X	X	X	X	X	X	X	X	X	X	X	X
I	I					I		I	I	I	I	I
X		X	X	X	X	X	X	X	X	X	X	X
									X	X	X	
I							I	I		I	I	
I	I	I			I			I	I	I	I	I
X		X		X	P		X	X	X	X	X	
						I					I	
X			X		P				X	X	X	P
X		X	X	X	P	X		X		X	X	X
X	P			X				X	X	X	X	X
	X	X		X	X				X	X	X	X
X	X	X	X		X	X	X	X	X	X	X	X
X		X	X	X		X	X	X	X	X	X	
X								X	X	X	X	
X	X				P						P	
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	P	X				X	X	X
X	X	X		X	X	X	X	X	X	X	X	X
X												
X	X	X	X	X	X	X	X	X	X	X	X	X
									X		X	
X	X		X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X		X	X	X	X	X
	X	X	X		X						X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
	X											
	X											
	P											
X	X											
X		X		X	P	X	X	X	X	X	X	X
X	X											
X	P							X	X	X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X
X	X		X	X	X	X	X		X	X	X	X
	X		X	X	X	X	X		X	X	X	X
X	X		X	X	X	X	X		X		X	X
X	X											
	X											P
X	X	X	X	X	X	X		X	X	X	X	X
X	X				X						X	X
69	83	43	50	50	62	56	42	56	61	67	76	70
69	68	43	46	50	52	55	41	56	61	67	75	65
4	4	2	1	1	2	2	1	4	3	4	5	3
0	15	0	4	0	10	1	1	0	0	0	1	5

Falls. If still present, it must be in very low numbers. The weed shiner was last taken at one station in 1961. It was previously reported from 11 stations on the St. Croix River in the early 1900's. The only voucher specimen of a mud darter was from a single station in the St. Croix River at Stillwater in 1928. If present today, it is in very low numbers. Although the river carpsucker has been reported regularly in fish surveys since the 1950's, it is not listed in this report for the reasons stated above on acceptance of records. Because the presence of these seven possibly extirpated species and nine of the species listed in Table 8 is based on only a few voucher specimens and locations, we request that anyone collecting specimens of these 16 species save one and contact us.

Significant differences in ichthyofauna occur between the mainstem of the lower St. Croix River, the mainstem of the upper St. Croix River, and in the lower and upper St. Croix River basins. Historically, 83 species of fish have been reported from the lower reach of the St. Croix River and only 70 species from the upper reach. Since 1975, 15 of these species have not been identified from the lower reach (Table 8) and 5 species (pallid shiner, pugnose shiner, weed shiner, trout-perch, and sauger) from the upper reach. This brings the number of species to 68 for the lower reach and to 65 for the upper reach. Since 1975, 22 species were found only in the lower reach and 18 species were found only in the upper reach (Table 9).

For the lower St. Croix River basin, 103 species were reported compared with only 84 for the upper basin. Since 1975, the number of species dropped to 95 for the lower St. Croix River basin and to 80 for the upper St. Croix River basin. The 22 species found only in the lower St. Croix River basin are the same as for the lower mainstem except that the rainbow darter in the lower basin is replaced with the warmouth in the lower mainstem. Seven species are found only in the upper St. Croix River basin (Table 10). Most of the species that occur only in the lower St. Croix River basin are species of large, deep, low-gradient river or lacustrine environments. Fishes such as paddlefish, gars, mooneyes, silver chubs, speckled chubs, emerald shiner, river shiner, buffaloes, highfin carpsucker, spotted sucker, warmouth, crystal darter, Western sand darter, and river darter probably colonized only the lower St. Croix River, where conditions were more like that of the Mississippi River. In addition, highfin carpsucker and speckled chub, as well as gizzard shad, skipjack herring, spotted sucker, and pugnose minnow, are in the northern limits of their ranges and would be rare anywhere in the St. Croix River. If any of these species are twentieth century arrivals to the St. Croix River, their expansion was curtailed by the dam regardless of their environmental tolerances.

When one looks at the differences between the mainstem of the St. Croix River and its tributaries of the lower St. Croix River basin, there are 24 species that are only found in the mainstem and 19 species that are only found in its tributaries (Table 10). There are fewer differences in the upper St. Croix River basin, with four species (silver lamprey, quillback, blue sucker, and flathead catfish) found only in the mainstem of the St. Croix River and 13 species that are found only in its tributaries (Table 10).

The diversity among the subbasins of the lower St. Croix River basin varies from a low of 28 species for the Kinnickinnic River basin to a high of 60 species for the Apple River basin; the average is 43 species (Table 7). Diversity among the subbasins of the upper St. Croix River basin is not as great, with a low of 42 species for the group of tributaries in Pine County, Minnesota (excluding the Kettle and Snake River basins), and a high of 67 species for the Namekagon River basin. Two important reasons for these differences are less agriculture and urban use, and generally larger basins in the upper St. Croix River basin.

Statistical data on the population trends and biomass of fish species in the St. Croix River could not be found.

Table 8. Fish species not collected in the lower St. Croix River after 1974.

Common name	Scientific name
Shovelnose sturgeon[a]	*Scaphirhynchus platorynchus*
Goldeye[a]	*Hiodon alosoides*
Skipjack herring[a]	*Alosa chrysochloris*
Pallid shiner[a]	*Notropis amnis*
River shiner[a]	*N. blennius*
Bigmouth shiner	*N. dorsalis*
Weed shiner[a]	*N. texanus*
Longnose dace	*Rhinichthys cataractae*
Yellow bullhead	*Ameiurus natalis*
Brown bullhead	*A. nebulosus*
Stonecat	*Noturus flavus*
Tadpole madtom	*N. gyrinus*
Banded killifish	*Fundulus diaphanus*
Mud darter[a]	*Etheostoma asprigene*
Least darter	*E. microperca*

[a] Not collected in entire St. Croix River basin.

Table 9. Fish species in one reach of the St. Croix River and not found in another reach or subbasin. Based on post 1974 collections only.

In lower mainstem but not in upper mainstem	In upper mainstem but not in lower mainstem	In upper St. Croix River basin but not in lower St. Croix basin
Paddlefish	Central stoneroller	Northern brook lamprey
Longnose gar	Brassy minnow	Southern brook lamprey
Shortnose gar	Pearl dace	Largescale stoneroller
Mooneye	Hornyhead chub	Pugnose shiner
American eel	Bigmouth shiner	Cisco or lake herring
Gizzard shad	Blackchin shiner	Lake trout[a]
Speckled chub	Blacknose shiner	Longear sunfish
Silver chub	Northern redbelly dace	
Emerald shiner	Blacknose dace	
Pugnose minnow	Longnose dace	
Highfin carpsucker	Creek chub	
Smallmouth buffalo	Yellow bullhead	
Bigmouth buffalo	Stonecat	
Spotted sucker	Tadpole madtom	
Blue catfish[a]	Central mudminnow	
White bass	Burbot	
Crystal darter	Banded killifish	
Western sand darter	Iowa darter	
Rainbow darter		
Fantail darter		
River darter		
Sauger		

[a] Introduced species.

Table 10. Differences in fish species between the upper and lower St. Croix River and basin. Based on post 1974 collections only.

In lower mainstem but not in its tributaries	In lower tributaries but not in lower mainstem	In upper tributaries but not in upper mainstem
Chesnut lamprey	American brook lamprey	Northern brook lamprey
Lake sturgeon	Central stoneroller	Southern brook lamprey
Paddlefish	Brassy minnow	Largescale stoneroller
Longnose gar	Hornyhead chub	Pugnose shiner
Shortnose gar	Blackchin shiner	Brown bullhead
Bowfin	Blacknose shiner	Cisco or lake herring
Mooneye	Northern redbelly dace	Rainbow trout[a]
American eel	Finescale dace	Brook trout
Speckled chub	Blacknose dace	Lake trout[a]
Silver chub	Creek chub	Trout-perch
Highfin carpsucker	Central mudminnow	Mottled sculpin
Blue sucker	Brook trout	Slimy sculpin
Smallmouth buffalo	Trout-perch	Least darter
Bigmouth buffalo	Burbot	
Spotted sucker	Mottled sculpin	
Greater redhorse	Slimy sculpin	
Channel catfish	Warmouth	
Flathead catfish	Iowa darter	
Brook silverside	Least darter	
White crappie		
Crystal darter		
Western sand darter		
Blackside darter		
Sauger		

[a] Introduced species.

The crystal darter is the only Wisconsin state endangered species found in the St. Croix River basin. In 1978 and 1982, only two specimens were found at two stations in the mainstem of the lower St. Croix River. At present, Minnesota does not list any fish species in the basin as endangered or threatened.

Wisconsin lists eight species (paddlefish, speckled chub, pugnose shiner, blue sucker, river redhorse, greater redhorse, longear sunfish, gilt darter) found in the St. Croix River basin as threatened. Of these threatened species, the paddlefish and speckled chub were found only in the lower St. Croix River, and the pugnose shiner and longear sunfish were found only in tributaries of the upper St. Croix River basin. The presence of the longear sunfish is based on the collection of 10 specimens at one station from the Yellow River in 1988 by T. Simon (U.S. Environmental Protection Agency, Chicago, Illinois, unpublished report).

The southern brook lamprey was first identified from the Namekagon River in 1982 by Cochran (1987). This population is separated by 900 km from the nearest population previously reported in southern Missouri. Other St. Croix River tributaries in which it is known to occur are Crooked Creek, Tamarack River, Little Sand Creek, and Hay Creek in Minnesota and Wood Creek in Wisconsin. The lake sturgeon is another species of special concern, and recently it has shown signs of decline (M.P. Engel, WDNR, Baldwin, Wisconsin, personal communication). In a cooperative effort, Minnesota and Wisconsin have angling rules that restrict the catch to one sturgeon/person/year, with a minimum length of 1.27 m. Minnesota has closed this fishery upstream of Taylor Falls, and hopefully, Wisconsin will follow Minnesota's lead so that this resource will be adequately protected.

Sport and Commercial Fisheries

Important sport fisheries in the St. Croix River basin include walleye, smallmouth bass, northern pike, brown trout, brook trout, channel catfish, lake sturgeon, and flathead catfish. The Kinnickinnic River and Valley Creek (Washington County, Minnesota) in the lower St. Croix River basin and Crooked Creek (Pine County, Minnesota) in the upper basin are renown for their trout fisheries. With over 1,725 lakes containing 25,084 ha in the basin, panfish play an important role in the sport fishery. Commercial fishing has never been a major industry. In the last few decades this fishery for common carp, freshwater drum, catostomids, and ictalurids has decreased even further and now is of minimal importance (R. Steward, WDNR, Fitchburg, Wisconsin, personal communication). With the exception of the lake sturgeon fishery, there are no records available to permit statistical analysis of their population trends.

Species Richness

K. Fausch (Colorado State University, Fort Collins, Colorado, unpublished report) developed an Index of Biotic Integrity (IBI) for 38 sites on the mainstem of the St. Croix River and 18 sites on the Namekagon River. The rationale behind IBI, and ensuing research developing this index for different regions, is presented by Karr (1981), Karr et al. (1984, 1985), and Fausch et al. (1984). Fausch's data came from the WDNR's Fish Distribution Data (Fago 1986). The changes from these methods were (1) the white sucker was used for the very tolerant species instead of the green sunfish, (2) the percent of specialized invertebrate feeders was substituted for the percent insectivorous cyprinids, and (3) a score of 3 was assigned

Table 11. Number of stations with their index of biotic integrity scores for sites along the mainstem of the St. Croix River.[a]

River reach	Excellent		Good		Fair		Poor
	57–60	53–56	48–52	45–47	39–44	36–38	28–35
Lake St. Croix			1			2	
Above L. St. Croix to St. Croix Falls			3	1	2	1	
Above St. Croix Falls to mouth of Namekagon		4	14	3	2	1	
Above mouth of Namekagon				2			

[a]Scores calculated by K. D. Fausch, Colorado State University, Ft. Collins, Colorado, unpublished report, using data collected from 1978 to 1979 (Fago 1986).

to the diseased fish metric because no data were available (a maximum score of 58 instead of 60 was possible). Fausch found that most sites on the St. Croix River downstream of the confluence of the Namekagon River scored in the fair, good, or excellent class of IBI (Table 11). He further showed that the greatest decline in large river fish species occurred at the St. Croix Falls.

T. Simon (U.S. Environmental Protection Agency, Chicago, Illinois, unpublished report) sampled two stations on the upper St. Croix River near Riverside, three more stations on the Yellow River, and one station on Loon Creek (tributary of the Yellow River). He used methodology similar to that of Fausch. Simon obtained IBI scores from excellent to good for all stations.

Mussels

Thirty-nine species of mussels have been identified from the St. Croix River basin (Table 12). The common and scientific names given in this report follow guidelines of the American Fisheries Society's Committee on Scientific and Vernacular Names of Mollusks, of the Council of Systematic Malacologists (Turgeon et al. 1988). These records come from the following sources: Wilson and Danglade (1914), Dawley (1944), Mathiak (1979), and Heath (WDNR, Rhinelander, Wisconsin, unpublished reports). Most collections were from the mainstem of the St. Croix River, with fewer samples from the Namekagon and Apple rivers. Data from 444 collections during 1987–89 revealed only 25 species from the upper St. Croix River, compared with 40 species for the lower St. Croix River. Blockage of upstream migration at St. Croix Falls is probably the most important reason for the differences (D. Heath, WDNR, Rhinelander, Wisconsin, personal communication). The differences in numbers of species collected during 1944, 1974–77, and 1987–89 are probably due to different sampling techniques and intensities of sampling. Only limited collections were made in 1944 and 39 in 1974–77.

The winged mapleleaf and Higgins eye are listed as endangered by the Federal Government; both are found only in the mainstem of the lower St. Croix River. Wisconsin lists these two species as endangered, along with seven other species (spectaclecase, purple wartyback, butterfly, elephant-ear, snuffbox, ebonyshell, sheepnose). At present, Minnesota lists Higgins eye and winged mapleleaf as its only endangered or threatened species. Wisconsin also lists the salamander mussel, pistolgrip, and monkeyface as threatened. The only Wisconsin endangered or threatened species found in the upper St. Croix River are the spectaclecase, purple wartyback, and salamander mussel.

The Asian clam (*Corbicula flaminea*) is present in the lower St. Croix River basin (D. Heath, Wisconsin Department of Natural Resources, Rhinelander, personal communication).

The zebra mussel has not been found in the St. Croix River basin. However, the possible invasion of this species into this basin is the single most important threat to the existence of not only the 12 Wisconsin endangered and threatened species but also all species of mussels in the St. Croix River basin.

Aquatic Invertebrates

In five studies since 1966, 497 taxa of aquatic invertebrates have been identified in the St. Croix River basin (Table 13). Scientific names used in this report conform to the following publications: Pennak (1989), Oliver et al. (1990), and Thorp and Covich (1991). Four of the five studies were conducted since 1988, identifying 332 species representing 235 genera and 100 families. For a complete listing of species in the Unionidae family, see the Mussels section above. Most invertebrates were collected on the mainstem of the St. Croix River, with a few on tributaries close to their confluence with the St. Croix River. Records came from the following sources: Wurtz (NSPC 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976), MWCC (1990), Jacobs (1990), G. Montz (and others, MDNR, St. Paul, Minnesota, unpublished report), and R. Lillie (WDNR, Madison, Wisconsin, personal communication). The lower St. Croix River basin had fewer total species (167) and fewer Insecta taxa (128) compared with the upper basin, which had 218 total species and 190 Insecta taxa. The total number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) was also smaller in the lower basin, 46 species compared with 113 species for the upper basin. The percent of EPT compared with total insecta was 36% in the lower basin and 59% in the upper basin, which indicates good water quality for the lower basin and even better water quality for the upper basin.

Table 12. Mussel species found in the St. Croix River basin, 1913–89.

		Wilson and Danglade 1913		Dawley 1944			Harold Mathiak 1974–77				David Heath 1987–89			
Common name	Scientific Name	Washington Co. basin	Pine Co. basin	Lower St. Croix River	Chisago Co. basin	Pine Co. basin	St. Croix River	Apple basin	Namek. basin	St. Croix basin	Lower St. Croix River	Upper St. Croix River	Namek River	St. Croix basin
	Unionoida, Unionidae													
Mucket	*Actinonaias ligamentina*			X	X	X	X			X	X	X	X	X
Elktoe	*Alasmidonta marginata*				X		X			X	X	X	X	X
Threeridge	*Amblema plicata plicata*		X	X	X	X	X	X		X	X	X	X	X
Giant floater	*Anodonta grandis*	X	X	X	X		X	X	X	X	X	X	X	X
Paper pondshell	*A. imbecillis*			X							X	X		X
Cylindrical papershell	*Anodontoides ferussacianus*				X		X	X	X	X	X		X	X
Spectaclecase	*Cumberlandia monodonta*										X	X		X
Purple wartyback	*Cyclonaias tuberculata*			X	X		X			X	X	X	X	X
Butterfly	*Ellipsaria lineolata*										X			X
Elephant-ear	*Elliptio crassidens*										X			X
Spike	*E. dilatata*			X			X		X	X	X	X	X	X
Snuffbox	*Epioblasma triquetra*										X			X
Ebonyshell	*Fusconaia ebena*										X			X
Wabash pigtoe	*F. flava*		X	X	X	X	X		X	X	X	X	X	X
Higgins eye	*Lampsilis higginsi*		X	X							X			X
Fatmucket	*L. silquoidea*	X	X	X	X		X	X	X	X	X	X	X	X
Plain pocketbook	*L. cardium*		X	X	X	X	X		X	X	X	X	X	X
White heelsplitter	*Lasmigona complanata complanata*		X	X				X		X	X	X		X
Creek heelsplitter	*L. compressa*				X	X		X		X	X	X	X	X
Fluted-shell	*L. costata*				X	X	X		X	X	X	X	X	X
Fragile papershell	*Leptodea fragilis*			X	X	X	X			X	X	X		X
Black sandshell	*Ligumia recta*		X	X		X	X		X	X	X	X	X	X
Washboard	*Megalonaias nervosa*			X							X			X
Threehorn wartyback	*Obliquaria reflexa*			X							X	X		X
Hickorynut	*Obovaria olivaria*			X	X		X			X	X	X	X	X
Sheepnose	*Plethobasus cyphyus*										X			X
Round pigtoe	*Pleurobema coccineum*			X		X	X			X	X	X	X	X
Pink heelsplitter	*Potamilus alatus*		X	X		X	X			X	X	X		X
Pink papershell	*P. ohiensis*			X							X			X
Winged mapleleaf	*Quadrula fragosa*										X			X
Monkeyface	*Q. metanevra*										X	X	X	X
Pimpleback	*Q. pustulosa pustulosa*		X	X			X			X	X			X
Mapleleaf	*Q. quadrula*		X								X	X		X
Salamander mussel	*Simpsonaias ambigua*										X	X	X	X
Squawfoot	*Strophitus undulatus*		X	X	X	X	X		X	X	X	X		X
Lilliput	*Toxolasma parvus*			X							X			X
Pistolgrip	*Tritogonia verrucosa*			X							X			X
Fawnsfoot	*Truncilla donaciformis*										X			X
Deertoe	*T. truncata*			X							X	X		X
Total species		2	12	24	14	11	18	6	9	20	39	24	16	39

Table 13. Number of specimens of aquatic invertebrates keyed to species and genera (in parentheses) collected in the St. Croix River basin, 1966–1991.

PHYLUM Class Order Family	Wurtz 1966–75 Lower St. Croix River	MWCC 1988 Lower St. Croix River	1988–91 Lower St. Croix River Basin	1988–91 Upper St. Croix River Basin	All 1988–91 St. Croix River Basin	All 1966–91 St. Croix River Basin
PORIFERA						
Spongillidae	X[a]					X
CYIDARIA						
Hydridae		(1)	(1)		(1)	(1)
PLATYHELMINTHES						
Planaridae	2			(1)	(1)	2 (1)
NEMERTEA						
Hoplonemertea	1					1
ROTIFERA						
Asplanchidae		(1)	(1)		(1)	(1)
Brachionidae		(1)	(1)		(1)	(1)
Lecanidae		(1)	(1)		(1)	(1)
Testudinellidae		(1)	(1)		(1)	(1)
Trichocercidae		(1)	(1)		(1)	(1)
NEMATOMORPHA						
Gordiidae	(1)					(1)
ENTOPROCTA						
Barentsiidae	1					1
ECTOPROCTA						
Lophopodidae	2					2
Paludicellidae	1					1
Pectinatellae	1			X	X	1
Plumatellidae	2					2
ANNELIDA						
Oligochaeta		X				
Enchytraeidae				X	X	X
Lumbriculidae	X					X
Naididae			10	8	13	13
Tubificidae	2 (2)		3	2 (1)	4 (1)	5 (1)
Hirudinae						
Erpobdellidae	1 (1)					1(1)
Glossiphoniidae	8 (1)					8 (1)
ARTHROPODA						
Crustacea						
Cladocera						
Bosminidae		1	1		1 (1)	1
Chydoridae			1		1	
Daphnidae		(2)	3 (1)		3 (1)	3 (1)
Leptodoridae			1		1	
Macrothricidae			1		1	
Sididae		(1)			(1)	(1)
Copepoda						
Cyclopidae		(1)	3 (1)		3 (1)	3 (1)
Diaptomidae		(1)	(1)		(1)	(1)
Peracarida						
Isopoda						
Asellidae	1		1	1	1	2
Amphipoda						
Grammaridae	2 (1)		1	1	1	3 (1)
Talitridae	1	1	1	1	1	1
Decapoda						
Cambaridae	1			1	1	1

Table 13. *Continued.*

PHYLUM Class Order Family	Wurtz 1966–75 Lower St. Croix River	MWCC 1988 Lower St. Croix River	1988–91 Lower St. Croix River Basin	All: Upper St. Croix River Basin	All: 1988–91 St. Croix River Basin	All: 1966–91 St. Croix River Basin
Insecta						
Ephemeroptera						
Baetidae	1 (6)	(2)	2 (2)	12 (2)	13 (3)	13 (6)
Baetiscidae	2			3	3	3
Behningiidae				1	1	1
Caenidae	(3)	(1)	(2)	3 (2)	3 (2)	3 (2)
Ephemeridae		1	1	1	1	1
Ephemerellidae	2 (3)	(1)	3	10	10	12
Heptageniidae	5 (2)	(1)	4	11 (1)	12 (1)	16 (1)
Leptophlebiidae	(1)	(1)	(1)	(2)	(2)	(2)
Metretopodidae	(1)					(1)
Oligoneuriidae			(1)	(1)	(1)	(1)
Potamanthidae				1	1	1
Siphlonuridae	3 (1)			(1)	(1)	3 (1)
Tricorythidae	1 (2)	(1)	(1)	(1)	(1)	1 (2)
Odonata						
Aeshnidae	(1)		1		1	1 (1)
Coenagrionidae	(13)	X	(1)	1 (2)	1 (2)	1 (13)
Corduliidae			1	1 (1)	2 (1)	
Gomphidae	(3)			3 (2)	3 (2)	3 (3)
Libellulidae	(1)		1		1	1 (1)
Macromiidae	(1)			(1)	(1)	(2)
Plecoptera						
Chloroperlidae				1	1	1
Leuctridae				X	X	X
Nemouridae			1	2	2	2
Perlidae	(2)		1	7	7	7 (2)
Perlodidae	3 (4)			4	4	6 (1)
Pteronarcyidae			(1)	(1)	(1)	(1)
Hemiptera						
Belostomatidae	(1)					(1)
Corixidae	2 (1)			X	X	2 (1)
Gerridae	(2)		1		1	1 (1)
Hebridae	X					X
Mesoveliidae	(1)					(1)
Nepidae	1 (1)					1 (1)
Pleidae	1		1		1	1
Saldidae	X					X
Veliidae			1		1	1
Neuroptera						
Sisyridae	(1)			(1)	(1)	(1)
Megaloptera						
Corydalidae	(1)			2	2	2 (1)
Sialidae	(1)		(1)		(1)	(1)
Trichoptera						
Brachycentridae			2	3	3	3
Glossosomatidae			(1)	(2)	(2)	(2)
Helicopsychidae				1	1	1
Hydropsychidae	(4)	(2)	4 (3)	15 (2)	16 (3)	16 (4)
Hydroptilidae	1 (1)	(2)	(2)	1 (4)	1 (4)	2 (4)
Lepidostomatidae			(1)	1	(1)	(1)
Leptoceridae	4 (14)		4	5 (1)	8 (1)	11 (8)
Limnephilidae	(2)		3 (3)	1 (2)	4 (3)	4 (4)

Table 13. *Continued.*

PHYLUM Class Order Family	Wurtz 1966–75 Lower St. Croix River	MWCC 1988 Lower St. Croix River	1988–91 Lower St. Croix River Basin	Upper St. Croix River Basin	All 1988–91 St. Croix River Basin	1966–91 St. Croix River Basin
Philopotamidae			2	2	4	4
Phryganeidae			(1)		(1)	(1)
Polycentropodidae	1 (6)	1(1)	(2)	(2)	(3)	1 (7)
Psychomyiidae	(3)			1	1	1 (2)
Rhyacophilidae	(2)			1	1	1 (1)
Sericostomatidae				(1)	(1)	(1)
Lepidoptera						
Pyralidae			X	(1)	(1)	(1)
Coleoptera						
Chrysomelidae	(3)					(3)
Curculionidae	(2)		(1)		(1)	(3)
Dryopidae	(1)		(1)	(1)	(1)	(1)
Dytiscidae	2 (8)		(2)		(2)	2 (10)
Elmidae	4 (5)		1 (3)	7 (3)	7 (3)	12 (1)
Gyrinidae	2 (3)		1	1	1	3 (2)
Haliplidae	2 (3)		(2)		(2)	2 (3)
Hydrophilidae	(6)		(3)	(1)	(3)	(8)
Psephenidae	(1)			(1)	(1)	(1)
Diptera						
Anthomyiidae	1					1
Athericidae			(1)	(1)	(1)	(1)
Blephariceridae	X			(1)	(1)	(1)
Ceratopogonidae	1 (3)		(3)	(2)	(4)	1 (6)
Chaoboridae		(1)	1		1	1
Chironomidae	28 (45)	X	14 (24)	14 (19)	28 (43)	46 (57)
Culicidae	(1)					(1)
Dolichopodidae	X					X
Empididae			(1)	(2)	(2)	(2)
Ephydridae	(1)					(1)
Muscidae	X					X
Psychodidae			(1)		(1)	(1)
Simuliidae			4	1 (1)	5	5
Stratiomyidae			(3)		(3)	(3)
Tabanidae	(1)		(1)	(1)	(1)	(1)
Tipulidae	X		(6)	(5)	(8)	(8)
Arachnida						
Hydracarina					X	(1)
MOLLUSCA						
Bivalvia[b]						
Corbiculidae						1
Sphaeriidae	1 (1)			(3)	(3)	1 (2)
Gastropoda						
Ancylidae	1					1
Hydrobiidae	2 (1)		(1)	(2)	(3)	2 (2)
Lymnaeidae	2		(1)		(1)	2 (1)
Physidae		(1)	(1)	(1)	(1)	(1)
Planorbidae	1 (3)			(3)	(3)	1 (5)
Pleuroceridae	1 (1)			(1)	(1)	1 (1)
Viviparidae	1					1
Total species represented	291	34	167	218	332	497
Total genera represented	180	32	150	171	235	344

Table 13. *Continued.*

PHYLUM Class Order Family	Wurtz 1966–75 Lower St. Croix River	MWCC 1988 Lower St. Croix River	1988-91 Lower St. Croix River Basin	All Upper St. Croix River Basin	1988–91 St. Croix River Basin	1966–91 St. Croix River Basin
Total families represented	80	32	73	70	100	120
Total Insecta	242	16	128	190	271	404
Total EPT[c]	80	15	46	113	129	170
Total EPT %[d]	33	94	36	59	48	42

[a] X = Keyed only to family.
[b] See Table 12 for complete listing of species in Unionidae.
[c] EPT = Number of taxa of Ephemeroptera + Plecoptera + Trichoptera.
[d] EPT % = EPT / Insecta.

However, the total number of families was nearly the same.

The pygmy snaketail is an endangered dragonfly in Wisconsin and is under review for listing by the Federal Government. The only other aquatic invertebrate (excluding mussels) that is listed as endangered or threatened or is proposed for listing by Wisconsin is the sand-burrowing mayfly. Minnesota does not have any aquatic invertebrates listed as endangered or threatened.

Endangered and Threatened Species in the Basin

Four federally listed endangered species (timber wolf, Higgins eye, winged mapleleaf, karner blue) and two threatened species (bald eagle, prairie bush clover) occur in the St. Croix River basin. However, the timber wolf is listed only as threatened in Minnesota, and the Prairie bush clover is listed only as threatened in Wisconsin.

The St. Croix River basin is a refuge for 40 of Minnesota or Wisconsin's endangered species (Table 14), and 36 threatened species (Table 15). Thus, 76 species that occur in the basin are listed by Minnesota or Wisconsin as either endangered or threatened. This is a considerable number considering there are only 107 species (58 endangered and 49 threatened) listed for all of Minnesota and 209 species (115 endangered and 94 threatened) for all of Wisconsin. This fact, along with the high diversity of all aquatic species, indicates a rich habitat diversity and thus a basin that is in relatively good shape.

Status of the Aquatic Resources

The St.Croix River basin supports a generally healthy and diverse invertebrate and fish community. Of the 18 Wisconsin basins listed by Fago (1992) and the 8 Minnesota basins listed by Underhill (1989), none is known to have more native fish species than the St. Croix. Nine of Wisconsin's 19 species listed as endangered or threatened are found in the basin. Three of these species (gilt darter, river redhorse, greater redhorse) are abundant in the St. Croix River mainstem and some of its tributaries. Of the 104 known native species of the basin, only seven may have become extirpated since 1889 (Table 8). With the possible exception of the shovelnose sturgeon, the St. Croix probably represented marginal habitat for these species even in presettlement times.

We believe that post settlement diversity in the basin has been maintained for a combination of reasons. The glacial tills and marine sedimentary bedrocks of the basin help maintain strong, permanent streamflow in the mainstem and most of its major tributaries. High permeability of many of the tills, a high percentage of vegetative cover, and a substantial percentage of wetlands minimize catastrophic flooding and streambank erosion. The latter two factors also help maintain water quality within most of the basin by reducing the runoff of nonpoint source pollutants—such as sediments, nutrients, and agricultural chemicals.

However, there is some reason for concern in certain areas of the basin. The Snake River subbasin is an example with 10 fewer fish species than the historical count, and those losses include lake

Table 14. List of federal and state endangered species in the St. Croix River basin. Data were obtained from Coffin and Pfannmuller 1988, and T. A. Meyer, WDNR, Madison, Wisconsin, personal communication.

Common name	Scientific name	Group	Status Wis.	Status Minn.	Status Fed.
Lynx	*Lynx canadensis*	Mammal	END[a]		C2[b]
Timber wolf	*Canis lupus*	Mammal	END	THR[c]	LELT[d]
Barn owl	*Tyto alba*	Bird	END		
Common tern	*Sterna hirundo*	Bird	END		C2
Loggerhead shrike	*Lanius ludovicianus*	Bird	END	THR	C2
Peregrine falcon	*Falco peregrinus*	Bird	END	END	
Red-necked grebe	*Podiceps grisegena*	Bird	END		
Trumpeter swan	*Cygnus buccinator*	Bird	END	END[e]	
Crystal darter	*Ammocrypta asprella*	Fish	END		C2
Goldeye	*Hiodon alosoides*	Fish	END		
Skipjack herring	*Alosa chrysochloris*	Fish	END		
Southern brook lamprey	*Ichthyomyzon gagie*	Fish	END		
Butterfly	*Ellipsaria lineolata*	Mussel	END		
Ebonyshell	*Fusconaia ebena*	Mussel	END		
Elephant-ear	*Elliptio crassidens cras.*	Mussel	END		
Higgins' eye	*Lampsilis higginsi*	Mussel	END	END	LE[f]
Purple wartyback	*Cyclonaias tuberculata*	Mussel	END		
Sheepnose	*Pleurobasus cyphyus*	Mussel	END		
Snuffbox	*Epioblasms triquetra*	Mussel	END		C2
Spectacle case	*Cumberlandia monodanta*	Mussel	END		C2
Winged mapleleaf	*Quadrula fragosa*	Mussel	END	END[e]	LE
Karner blue	*Lycaeides samuelis*	Butterfly	END		LE
Pygmy snaketail	*Ophiogomphus howei*	Dragonfly	END		C2
Alpine milk vetch	*Astragalus alpinus*	Plant	END		
Bog bluegrass	*Poa paludigena*	Plant	THR	END	C2
Brook grass	*Cetabrosa aquatica*	Plant	END		
Carolina anemone	*Anemone caroliniana*	Plant	END		
Cross milkwart	*Plygala cruciata*	Plant		END	
Dotted blazing star	*Liatris punctata var nebraskana*	Plant	END		
Fassett's locoweed	*Oxytropis campestris var chartacea*	Plant	END		
Kitten tails	*Besseya bullii*	Plant	THR	END	
Mountain cranberry	*Vaccinium vitis-idaea*	Plant	END		
Prairie bush clover	*Lespedeza leptostachya*	Plant	END		LT[g]
Prairie plum	*Astragalus crassicarpus*	Plant	END		
Ross' sedge	*Carex rossii*	Plant		END[e]	
Rough-seeded fameflower	*Talinum rugospermum*	Plant		END	
Rough white lettuce	*Prenanthes aspera*	Plant	END		
Sand violet	*Viola fimbriatula*	Plant	END		
Small skullcap	*Scutellaria parvula var parvula*	Plant	END		
Spotted pondweed	*Potamogeton plucher*	Plant	END		
Tubercled rein-orchid	*Platenthera flava var herbiola*	Plant	THR	END	
Wild petunia	*Ruellia humilis*	Plant		END	

[a] END = endangered.
[b] C2 = candidate, under review for listing.
[c] THR = threatened.
[d] = LT in Minn. and LE in Wis.
[e] = proposed.
[f] LE = legally endangered.
[g] LT = legally threatened.

Table 15. List of federal and state threatened species in the St. Croix River basin. Data were obtained from Coffin and Pfannmuller 1988, and T. A. Meyer, WDNR, Madison, Wisconsin, personal communication.

Common name	Scientific name	Group	Status		
			Wis.	Minn.	Fed.
Acadian flycatcher	*Empidonax virescens*	Bird	THR[a]		
Bald eagle	*Haliaeetus leucocephalus*	Bird	THR	THR	LT[b]
Cerulean warbler	*Dendroica cerulea*	Bird	THR		
Great egret	*Casmerodius albus*	Bird	THR		
Greater prairie-chicken	*Tympanuchus cupido*	Bird	THR		
Kentucky warbler	*Oporornis formosus*	Bird	THR		
Osprey	*Pandion haliaetus*	Bird	THR		
Red-shouldered hawk	*Buteo lineatus*	Bird	THR		
Blue sucker	*Cycleptus elongatus*	Fish	THR		C2[c]
Gilt darter	*Percina evides*	Fish	THR		
Greater redhorse	*Moxostoma valenciennesi*	Fish	THR		
Longear sunfish	*Lepomis megalotis*	Fish	THR		
Paddlefish	*Polyodon spathula*	Fish	THR		
Pugnose shiner	*Notropis anogenus*	Fish	THR		
River redhorse	*Moxostoma carinatum*	Fish	THR		
Speckled chub	*Macrhybopsis aestivalis*	Fish	THR		
Buckhorn	*Tritogonia verrucosa*	Mussel	THR		
Monkeyface	*Quadrula metanevra*	Mussel	THR		
Salamander mussel	*Simpsonaias ambigua*	Mussel	THR		
Blanding's turtle	*Emydoidea blandingii*	Turtle	THR	THR	C2
Wood turtle	*Clemmys insculpta*	Turtle	THR	THR	
Regal fritillary	*Speyeria idalia*	Butterfly	THR		C2
Tiger beetle	*Cicindela macra macra*	Insect		THR[d]	
Tiger bettle	*Cicindelapatruela patruela*	Insect		THR[d]	
Sand-burrowing mayfly	*Dolania americana*	Insect	THR		
Algal-leaved pondweed	*Potamogeton confervoides*	Plant	THR		
Braun's holly fern	*Ploystichum braunii*	Plant	THR		
Brittle prickly-pear	*Opuntia fragilis*	Plant	THR		
Calypso orchid	*Calypso bulbosa*	Plant	THR		
Illinois tich-trefoil	*Desmodium illonoense*	Plant		THR	
Marsh grass-of-parnassus	*Parnassia palustris*	Plant	THR		
Prairie thistle	*Cirsium hillii*	Plant	THR		C2
Sand reed	*Calamovilfa longifolia*	Plant	THR		
Small round-leaved orchis	*Amerorchis rotundifolia*	Plant	THR		
Snow trillium	*Trillium nivale*	Plant	THR		
Sweet coltsfoot	*Petasites sagittatus*	Plant	THR		
Tooth-cup	*Rotala ramosior*	Plant		THR[d]	

[a] THR = threatened.
[b] LT = legally threatened.
[c] C2 = candidate, under review for listing.
[d] = proposed.

sturgeon, quillback, brook trout, trout-perch, burbot, and Iowa darter, which suggests the possibility of deteriorating habitat because all of these species except the lake sturgeon are doing well elsewhere in the basin. We also know that although the water quality of the Snake River is generally good, there are tributary areas of nutrient loading and local streambank erosion. The only other subbasin whose species count has declined by more than one is the Chisago County tributaries in Minnesota (Table 7). The declines have come in the Sunrise River subbasin, which has undergone more urbanization and stream modification in the last two decades than any other subbasin. We do not claim

cause and effect here; we merely point out circumstances that merit further observation and investigation.

Although much descriptive data exist about aquatic biota in the basin, there are no population studies of fishes or invertebrates that permit analysis of population trends. Stewart and Gilbertson (MDNR, St. Paul Minnesota, unpublished report) summarized gillnet and trapnet catches in Lake St. Croix for 1967–88, but no statistical analysis was conducted because of differences in sampling designs among studies. The authors characterized catches of most species (common carp, sucker species, channel catfish, northern pike, sauger, black crappie, white crappie) as steady over the period. Freshwater drum catches increased, white bass, and gizzard shad catches were erratic, and walleye declined between 1975 and 1983 but returned to late 1960's levels in 1988. In 1988 and 1989, Montz (and others, MDNR, St. Paul, Minnesota, unpublished report) repeated the 1959 electrofishing study (Kuehn et al. 1961) of the mainstem from the Namekagon River to the Apple River. Only general comparisons of the two studies can be made because catch rates were reported in broad ranges by Kuehn et al. Most species' catch rates were fairly similar in the studies. However, blue sucker, largemouth bass, and especially lake sturgeon showed clear and substantial declines in catch rates.

One of the obstacles to watershed-based management in the St. Croix basin is the incredible tangle of regulatory and managerial responsibility that exists. The tangle is worse than usual because of the St. Croix's status as one of the nation's wild and scenic rivers. By our count, there are 9 federal agencies and services, 25 state administrative units, 4 joint commissions, and an uncounted number of county and local governmental units involved in monitoring, regulating, and managing the waters and lands within the St. Croix River basin. As we discovered in our research for this paper, virtually no one has a very clear total picture of what goes on in the basin. We still do not. Clearly, there is a need to open better lines of communication and to set up mechanisms to encourage a wider base of participation in developing and implementing management plans. Federal, state, and local authorities must work together to develop comprehensive land-use policies that provide for land-based needs but minimize wetland development, accelerated erosion, and runoff from agricultural fields and urban areas. Management of stream resources cannot be effective without compatible land management plans.

An historic step in this direction has just been completed with an agreement to formulate a cooperative basin-wide water quality management plan for the St. Croix River basin. The National Park Service and the states of Minnesota and Wisconsin have signed a St. Croix Basin Water Quality Plan Agreement. This agreement requires the Minnesota–Wisconsin Boundary Area Commission (MWBAC) to assist in the planning and coordination of studies and conservation efforts called for in the agreement. The objectives of this agreement are (1) to formulate a plan for the entire St. Croix River basin that will identify, monitor, and control adverse threats and effects to its water quality; (2) to develop this plan of study by June 1993 and a complete plan by June 1995; (3) to implement this plan on a priority watershed basis within the basin; (4) to act as a forum for local governments and the public; and (5) to review and update this plan (MWBAC, Hudson, Wisconsin, unpublished report). This agreement along with the St. Croix River basin water quality management plan for Wisconsin (WDNR, Madison, Wisconsin, unpublished report) are historic first steps in having the entire St. Croix River basin under an ecosystem type management plan. WDNR's St. Croix Basin Water Quality Management Plan has 26 pages of recommendations that should be looked at closely when formulating the basin-wide management plan.

This agreement between Minnesota, Wisconsin, and the U.S. National Park Service will help open the lines of communication between federal, state, and local agencies and public or private organizations. Their efforts will be instrumental in preserving the unique natural resources in the St. Croix River basin and will serve as a model for other basins that cross state boundaries.

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The Vermillion River: Neither Red nor Dead

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Abstract. The Vermillion River is a small Missouri River tributary in eastern South Dakota. Its basin encompasses 5,800 km^2 and drains fertile soils formed from glacial drift. Stream flows are variable and range from 0 to >606 m^3/s. In some years water flows only in the lower 29 km of the river's 220-km length. The hydrologic cycle exhibits two periods of high streamflows; the largest, in early spring, results from melting snow, while the second is associated with heavy rainfall in early summer. Ninety-six percent of the basin's land is in agriculture. Anthropogenic changes in the watershed and main channel have been extensive and include main channel, floodplain, and upper watershed alterations. Moreover, degradation of basin potholes and marshes has reduced storage capacity, contributed to discharge variability, and transformed a pool and riffle stream with gravel substrate into a slow-moving, turbid river with a silty substrate. About 45–50 species of fish inhabit the streams of the basin, including one exotic species, common carp (*Cyprinus carpio*), nine species introduced from adjacent drainage basins, and one native threatened species, plains topminnow (*Fundulus sciadicus*). Species adapted to cool, clear headwater streams have been declining since Caucasian settlement. Despite watershed changes resulting from agrarian activities, the ichthyofauna of the basin has been stable over the last 35 years. Perhaps this river's most important function is its contribution to community metabolism of its parent stream, the Missouri River. A biocentric management philosophy for all river systems is advocated, if we are to retain viable lotic fisheries.

The origin of this river's name is uncertain, although when Lewis and Clark crossed this Missouri River tributary in 1804 enroute west they called it the Whitestone River (U.S. Army Corps of Engineers 1952). However, when they returned past this same location in 1806, they noted passage over the Redstone River. The first name was probably an incorrect translation of Sioux names for the river that included "wase spa," which means red paint, and "killa kalick," which means red wood. The former referred to red clay outcroppings, which occur in a few locations, and the latter to the color of young willow stems and fall sumac foliage that abound on the floodplain. French trappers were the first Caucasians to settle at the river's mouth, and the term "red" in the original Indian

names was probably translated as "vermillion" by the trappers (Moses 1976). However, there is no documentation for this substitution.

The Vermillion River is one of the small tributaries that enter the middle Missouri River along its eastern bank. Most east bank tributaries have small drainage basins and poorly developed surficial drainage of Pleistocene glacial drift and till (Flint 1955). Poor drainage evoked a quick response by the first Caucasian settlers. Although the basin's land was not settled for agrarian purposes until the latter half of the 19th century, anthropogenic changes in the water drainage pattern followed quickly. Settlers handled drainage problems by tiling and other procedures (Schell 1985). Subsequently, public-supported drainage projects were approved and completed. Indeed, these efforts were initiated within 50 years of settlement. Plans for dredging and ditching of the Vermillion River were approved by the Clay County commissioners in 1910 and completed by 1913 (Moses 1976).

Intensified draining of the fertile basin soils and breaking of the prairie sod had an immediate effect on stream channel morphology and other river parameters. Early photographs of the Vermillion River indicate that it was a stream of outstanding beauty with numerous hairpin curves (Moses 1976). It probably consisted of pools and riffles with gravel and sand substrates, although there is no description of the pristine river in the historic records. However, human activities quickly altered the pristine state and resulted in a river with varied discharge, a shortened channel, and a predominantly silt substrate. The riverine and riparian biotic communities were altered by the erosion of the uplands and deposition of alluvium on the floodplain. In this paper, we describe the Vermillion River basin and its fishery resources and discuss how anthropogenic decisions have affected this natural resource.

Historical Description

Morphometry and Hydrology

The Vermillion River basin encompasses about 5,800 km^2 in southeastern South Dakota (Fig. 1). The basin is oriented along a north–south axis and measures 242 km long, with widths varying from 19.2 to 58.0 km (Lowe 1977). The river is a fourth- or fifth-order stream, and its principal tributaries include Clay, Baptist, Saddlerock, Turkey Ridge, and Long creeks.

The basin topography is characterized by moderately undulating uplands and hills bordering the stream valleys. Turkey Ridge attains an altitude of 535 m, the highest elevation in the basin. From about 18 km below Centerville to 3 km above Vermillion, the Vermillion River channel has been straightened, dredged, and restrained by levees. In addition, similar channel modifications were inflicted on Clay Creek, which drains an extensive area on the Missouri River floodplain, which lies in the drainage basin.

The base of the Vermillion River basin consists of igneous and metamorphic rocks of Precambrian age. This base is overlain by sedimentary strata of Paleozoic and Mesozoic age. The topsoil consists of unconsolidated glacial deposits and alluvium of Quaternary age. During the Pleistocene epoch, several ice sheets advanced across all or part of the Vermillion River basin.

The glaciers dramatically altered the topography and drainage patterns of pre-Pleistocene time. Formation of the Vermillion River trench probably started when the most recent glacier retreated about 12,000 years ago. Meltwater from the wasting ice carved a deep trench in the glacial deposits that had been established in the valley of the ancient White River. Continued erosion has created the existing valley. Because the valley was created by streams with greater volumes during the glacial melt, the current Vermillion River is considered an underfit river. Consequently, the width of the existing valley could accommodate a river with considerably more volume.

Following the retreat of the most recent glacier, prevailing westerly winds carried silt and fine sand from the outwash plains of the Missouri and Vermillion rivers and deposited this material as loess and dune sand on adjacent uplands. Erosion of the uplands and deposition of alluvium have been the principal geological processes operating since the retreat of the last glacier (Lowe 1977).

Glacial drift masks the previous topography, including preglacial valleys. Many of these former valleys contain outwash deposits of sand and gravel, which serve as excellent aquifers. The subsurface drainage into the Vermillion River contributes significantly to its streamflow. Indeed, after early July, the Vermillion River streamflow is sustained largely by groundwater runoff (Lowe 1977).

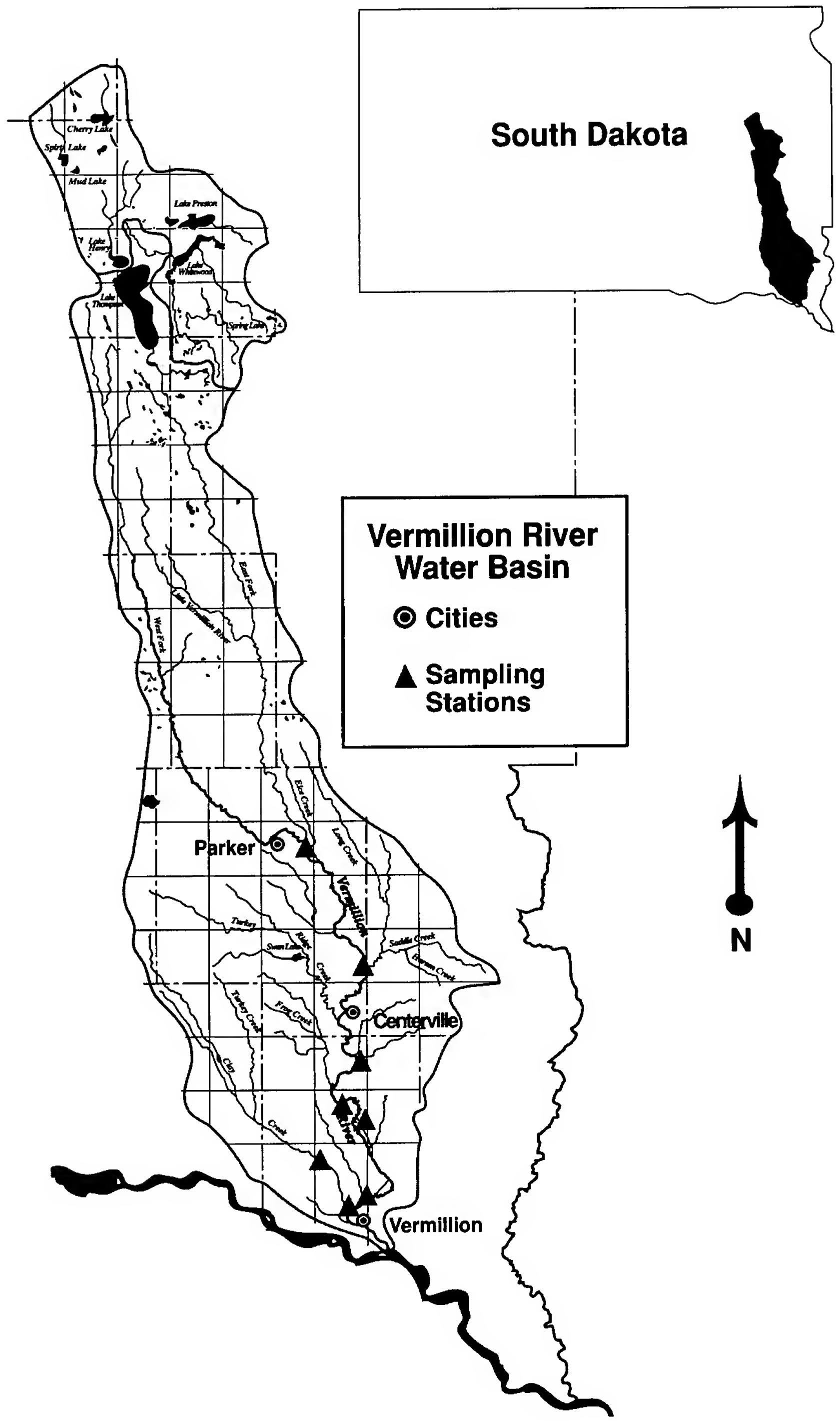

Fig. 1. Vermillion River basin depicting sampling stations used in 1956–59 and 1991.

There are two periods of flooding in the annual hydrologic cycle of the Vermillion River. The largest streamflows occur in early spring following snowmelt. At this time, the streamflow average of 3.54 m^3/s (125 cfs) is exceeded in 50% or more of the years of record (Lowe 1977). A secondary peak is associated with heavy rainfall in early summer, usually in June. Lowest streamflow volumes occur in midwinter, when total precipitation is light and temperatures remain below freezing.

Flooding in the Vermillion River basin probably occurs almost every year, according to streamflow

records maintained since 1944 (Lowe 1977). Even in drought years, ice jams during early spring often cause the river to temporarily overflow its banks. The duration of flooding in the mainstem valley is usually from 1 to 3 weeks. This relatively long flooding period is caused by a low stream gradient and the high storage potential of the valley. Except for Clay Creek, flood duration on the tributaries is short. Mainstem flood duration is also influenced by water levels in the Missouri River. Water levels are controlled by the U.S. Army Corps of Engineers through water releases from the Missouri River mainstem dams. One of the primary purposes of the mainstem dams is flood control (Hesse et al. 1989). During the June rise of the Missouri River, water releases from Gavins Point Dam are decreased to compensate for increased water volumes from downstream tributaries. In late summer and fall, more water is released from the mainstem dams than would occur in an uncontrolled Missouri River.

The mean annual discharge volume for the period from 1945 to 1975 was 3.2 m^3/s (113 cfs), and the median was 1.86 m^3/s (80 cfs; Lowe 1977). There is marked variability in streamflow volumes, and the discharge equals or exceeds the mean annual discharge about 25% of the time. The maximum discharge volume was recorded 4.3 km north of Vermillion, South Dakota, in June 1984, when the volume reached 606 m^3/s (21,400 cfs; Hoffman et al. 1987). On numerous occasions, zero flows have been recorded at each of the permanent gauging stations. During drought years, water flows only in the lower 29 km of the river's 220-km length.

Areas mantled by glacial drift, such as the Vermillion River basin, are generally characterized by numerous shallow marshes and lakes. Many of these were drained or obliterated by agrarian activities. Significant surface-water resources in the Vermillion River basin include 27 natural lakes and artificial impoundments on the mainstem and the principal tributaries (Table 1). These lakes have a total area of 13,686 ha and include, Lake Thompson, 6,571 ha, the largest natural lake in South Dakota. However, Lake Thompson and the other lakes in Kingsbury County (Table 1) lie in a noncontributing drainage area of about 1,035 km^2, which consists mostly of poorly drained glaciated terrain. Surface runoff seldom overflows into the Vermillion River basin, although the area contributes ground water to the basin (Hamilton 1989). In addition to the lakes there are an estimated 2,915 dugouts and stockponds, which cover 743 ha. Exclusive of streams, the total surface water in the Vermillion River basin is about 14,429 ha.

The Vermillion River basin has a subhumid continental climate with widely fluctuating temperatures and precipitation. The mean annual precipitation is 61 cm, 75% of which falls during the growing season. Mean daily temperature in January, the coldest month, is 9.4° C, and in July, the warmest month, is 22.8° C.

The vegetative cover of the basin at the time of settlement consisted of tall-grass prairie on the upland and forests along the major stream floodplains. At present, the lower 70 km of the river is bordered by a riparian forest, which grows principally within the stream-to-dike margin. Pasture grasses and agricultural crops constitute the riparian vegetation in the upper reaches. About 96% of the basin's area is devoted to agriculture, and 82% is cropland. Less than 1% of the land is publicly owned (Lowe 1977).

Evaporation and irrigation are the primary consumers of water from the Vermillion River basin. The mean annual lake evaporation rate is 93.9 cm, which results in a total evaporative loss from the lakes, dugouts, and stock dams of 13.55×10^7 m^3. This amount represents almost 50% of the total surface water storage capacity (28.5028×10^7 m^3) and underscores the importance of ground water in maintaining surface water levels in the basin. Irrigators in the Vermillion River basin procure almost all of their water from groundwater aquifers using center pivot systems to apply water to primarily corn and soybean fields (Lowe 1977). Municipal water also comes from groundwater aquifers.

Water Quality

Generally, surface water from the Vermillion River basin is fresh, hard, and of the calcium sulfate type (Lowe 1977). Water quality varies temporally and with discharge rates. In spring, when surficial runoff is high and the water has limited contact with soluble soil materials, the water has a total dissolved solids (TDS) concentration of about 400 mg/L. Water entering the river primarily from groundwater sources during periods of low flow has a much higher TDS level. This is reflected in TDS levels found in late spring, summer, and fall that are twice (>900 mg/L) those found in spring (Table 2). Water quality of the ground water entering the Vermillion River varies considerably with location, quantity of water,

Table 1. Lakes of the Vermillion River basin. All lakes from Kingsbury County are found in an area where the surficial drainage makes a minimal contribution to the basin.

Lake	County	Surface area (ha)	Estimated storage capacity (m^3)
South Cherry	Kingsbury	195	2.3986×10^6
Henry	Kingsbury	893	1.362×10^7
Marten	Kingsbury	65	493,600
Mud	Kingsbury	183	2.229×10^6
Preston	Kingsbury	2,213	3.220×10^7
Spirit	Kingsbury	546	8.323×10^6
Thompson	Kingsbury	6,571	1.830×10^8
Whitewood	Kingsbury	2,010	2.452×10^7
Baureles	McCook	24	370,200
Bollingers	McCook	20	246,800
Forsch	McCook	101	740,400
Gross	McCook	40	617,000
Lions	McCook	28	518,280
McCullough	McCook	20	246,800
Schimmels	McCook	24	296,160
Tuschens	McCook	40	493,600
E. Vermillion[a]	McCook	223	8.100×10^6
Silver	Hutchinson	134	1.480×10^6
Silver	Miner	36	666,360
Loss	Minnehaha	40	617,000
Marion	Turner	1	18,510
Mud	Turner	61	370,200
Ross Crosley	Turner	65	393,600
Swan	Turner	74	898,352
Marindahl[a]	Yankton	60	1.970×10^6
Rose	Clay	11	128,336
Olson	Clay	8	121,969
Totals		13,686	28.5028×10^7

[a]Artificial impoundment.

source of recharge, percolation of water used in agriculture, and sometimes, depth of the aquifer from which it came. The South Dakota Geological Survey has voluminous data on the water quality of ground water, especially from aquifers in the lower basin (Christensen and Stephens 1967). These ground waters tend to be hard, slightly saline, well buffered, and alkaline, with excessive quantities of iron, manganese, sulfates, and other dissolved solids, when compared with U.S. Public Health Standards. These ground waters require softening and iron removal for domestic uses.

The fertile soils of the basin probably ensure that primary productivity rates are reasonably high. There are no published estimates of aquatic primary productivity in any of the basin's waters. However, algal standing crops were estimated indirectly from chlorophyll *a* determinations in Vermillion and Marindahl lakes (Schmidt 1967). These lakes had moderate to substantial chlorophyll *a* concentrations in summer and fall, 0.45–9.12 mg/L, when blue-green algae predominate in most South Dakota natural lakes. Primary productivity from all lakes in the basin probably is not a major contributor of carbon to the river system. However, riparian vegetation in the upper two-thirds of the river system consists of pasture grasses and agricultural crops. Presumably, as in other prairie rivers, this portion of the lotic ecosystem tends to be autotrophic (Wiley et al. 1989).

Biotic Communities

The biotic communities of the mainstem Vermillion River and its tributaries have not been extensively studied. Indeed, there were no studies of the ichthyofauna before 1925, fully 65 years after the

Table 2. Water quality of the Vermillion River from Gauging Station 6-4790 near Wakonda, South Dakota; Lake Marindahl (Clay Creek); and Lake Vermillion. All values expressed as milligrams per liter except as indicated.

	Vermillion River[a]			Lake Marindahl[b]	Lake Vermillion[b]
Date	31 May 1960	10 October 1960	17 March 1961	7/65–7/66	7/65–7/66
Discharge (m^3/s)	6.17	0.68	19.8		
Turbidity (JTU)	22–67	21–62			
Total dissolved solids	931	965	412		
Specific conductance K_{25} (S/cm^{-1})	1,180	1,240	593	827–1,650	335–555
pH	7.6–8.5	7.8–9.3			
Nitrogen	3.1	1.8	9.6	0.1–0.7	0.1–0.4
Phosphates	0.09–0.55	0.16–2.12			
Iron	0.02	0.03	0.07	0.06	0.08
Manganese	0.1	0.66	0.67	0.11	0.33
Sodium	35	34	11	23–31	9–16
Potassium	8.7	8.2	12	16–20	12–14
Total alkalinity	280	324	174	126–156	115–137
Sulfate	439	467	155	345–450	105–210
Chloride	5.6	6.2	0.0	5.1	3.5
Total hardness	627	674	279	336–415	193–328
Calcium	149	181	79	88–113	26–49
Magnesium	62	54	20	21–30	31–50

[a]Lowe (1977).
[b]Schmidt (1967).

basin was settled. Everman and Cox (1896) sampled fishes in the Missouri River basin, but none from the Vermillion River. Churchill and Over (1933) surveyed the fishes of South Dakota between 1926 and 1928. Their sampling sites were not identified, but presumably some collections were made in the Vermillion River basin. Bailey and Allum (1962) noted that limited sampling of fishes occurred in the basin during the 1930's and 1940's. The only previous definitive study of the ichthyofauna until the present study was conducted between 1956 and 1959 (Underhill 1959). The results of this study will be discussed later.

In the 1960's and 1970's several biologists, primarily from the University of South Dakota, studied the distribution of microcrustaceans, macroinvertebrates, mussels, and fishes in tributaries and the mainstem Vermillion River. Kawatski and Schmulbach (1967) noted that the smaller species of eucopepods and cladocerans were more abundant than larger species and that Vermillion's municipal sewage had an enriching effect on these microcrustaceans. Standing crops of macroinvertebrates and fish were studied in Say Brook, an intermittent headwater stream of Clay Creek (Kazmierski 1966). This tributary supported a fish community of 13 species, including the plains topminnow (*Fundulus sciadicus*), which is currently listed as threatened in South Dakota. The fish assemblage present represented species that originally inhabited clear pools of spring-fed prairie streams but adapted to changes caused by agrarian development (Cross and Moss 1987). The most abundant invertebrates were chironomids, oligochaetes, crayfish, and fingernail clams. Carlson (1964) studied the age and growth of the stonecat (*Noturus flavus*) in the Vermillion River, a species Underhill (1959) considered rare. Buchholz and Buchholz (1974) sampled and qualitatively defined the flora and fauna of four sites in the east fork of the Vermillion River. They noted the presence of only two fish genera, *Notropis* and *Etheostoma*.

Perkins (1975) completed the only invertebrate distributional study of the Vermillion River basin. This study involved unionid mussels (Pelycepoda), which are good monitors of stream pollution because of their longevity, limited mobility, and manner of feeding (i.e., filter feeding). They are vulnerable to excessive siltation and chemical pollutants. The Vermillion River unionid community formerly contained 14 species based upon the shells of dead specimens. In 1975 only nine living species were

found, and two species, the giant floater (*Anodonta grandis*) and the white heel-splitter (*Lasmigona complanata complanata*), constituted 82.4% of all living mussels. Both species are ecological generalists and subsist on a variety of substrates. The pocketbook (*Lampsilis ventricosa*) and other species of *Lampsilis* were formerly common in the river but were eliminated from the basin years ago, probably because they were less tolerant to changes in the substrate and water quality caused by agrarian activities. Starrett (1971) noted that *L. ventricosa* was eliminated by siltation and pollution from the Illinois River between 1918 and 1930.

Fisheries

The Vermillion River mainstem fishery has never been studied or managed, but the fish community is exploited, especially in the lower 29 km, where the river flows continuously. The fishing pressure has temporal and diel peaks. In early spring, a modest upstream spawning migration of northern pike (*Esox lucius*) attracts anglers, and even some of the tributaries, such as Clay Creek, absorb some of this pressure. Another segment of the angling public directs its efforts towards channel catfish (*Ictalurus punctatus*), and much of this effort is nocturnal during spring and summer. Other anglers fish the Vermillion River simply because of its proximity to their residences. Finally, a few very proficient boat anglers seeking game fish regularly fish the confluence of the Vermillion and Missouri rivers successfully.

Present Investigation

In the past 2 decades lotic ecosystems have received considerable attention by aquatic ecologists. Although much of this effort has been directed towards understanding energetic transfers and processes, the ichthyofauna received considerable attention. Unfortunately, fish communities in the Vermillion River were ignored until we initiated the present investigation in 1991. The results of this effort were compared with those of Underhill (1959), who completed the only other fish survey of the river. The time lapse between studies represents about 35 years, during which there have been few substantive changes in the Vermillion River basin.

Methods

Fish collections at 27 locations in the Vermillion River basin were made by J. C. Underhill from 1956 to 1959. Sampling sites used during this period (Time 1) were located on the main channel and tributaries of the Vermillion River. At each site about 150 m of stream, encompassing riffles, pools, and runs, was sampled for 1 h with a 6.4-mm mesh minnow seine.

We sampled fish at 15 sites throughout the basin during summer 1991 (Time 2). At each site, we collected fish in a single riffle, pool, and run with a 9.1-m electric seine (Bayley et al. 1989; Angermeier et al. 1991). The electric seine was powered by a 2,750-watt generator with a maximum output of 20 A. Two passes between block nets (6.4-mm mesh) constituted the sampling effort for each site. Six of the 15 sites sampled during 1991 were also sampled during Time 1. Two additional sites sampled during 1991 were located in a similar stream reach as those sampled during Time 1. We considered these sites as being similar to those used by Underhill (1959), resulting in eight sites where direct comparisons were possible (Fig. 1). All fish were collected during the summer months in both time periods.

Statistical Analysis

The use of different sampling gears and methods during each time period created a bias in the comparison of fish collections. An electric seine captures more species than a minnow seine (Bayley et al. 1989), and electrofishing is selective for larger individuals, whereas a minnow seine tends to select for smaller individuals. In the Vermillion River, however, large-bodied individuals of certain species (e.g., walleye, *Stizostedion vitreum*; shortnose gar, *Lepisosteus platostomus*; freshwater drum, *Aplodinotus grunniens*) collected with the electric seine were also captured with the minnow seine at many sites sampled during Time 1. (J. C. Underhill, University of Minnesota, Minneapolis, personal communication). To offset the bias that could be associated with gear size selectivity and capture efficiency, we used the presence or absence of a species as the only criterion and disregarded fish size and number of each species in a sample. As a result, several small fish of a single species collected during Time 1 were equally weighted with a single large individual of the same species collected during Time 2. Weighting collections in this manner was appropriate because our main objective was to determine trends in the

presence or absence of species between the two periods. Lack of complete quantitative records from the 1956–59 collections prevented us from evaluating changes in species density.

Collections from riffles, pools, and runs were combined for each of the eight common sample sites to obtain a species list for each site. We suspected that the siltation rate might be the major environmental parameter that changed between the two studies. Because siltation affects the reproductive capabilities of fish in agricultural streams (Berkman and Rabeni 1987), all species were assigned to broad, general reproductive guilds (Balon 1975; Pflieger 1975; Berkman and Rabeni 1987). Litho-pelagophils and phyto-lithophils were assigned to generalized lithophil and phytophil guilds.

We compared the number of sites where species in lithophil and phytophil guilds were present in both periods. Sample size was too small for adequate comparison of pelagophil, psammophil, speleophil, and miscellaneous guilds. We hypothesized that the median number of sites in which lithophils and phytophils occurred was similar between both collection periods. We used a median test (SAS Institute 1985) to test this hypothesis. If the medians were statistically different, this would indicate a net increase or decrease in the number of sites where both groups occurred. We also analyzed the occurrence of individual species within guilds with a median test to determine single-species changes between periods. Scores of 0 (absent) or 1 (present) were assigned to species at each site for this test.

Results

Underhill (1959) reported 49 species in the Vermillion River based on 1956 to 1959 and historic collections (Table 3). Six of these species (silver lamprey, *Ichthyomyzon unicuspis*; longnose gar, *Lepisosteus osseus*; American eel, *Anguilla rostrata*; burbot, *Lota lota*; paddlefish, *Polyodon spathula*; and shovelnose sturgeon, *Scaphirhynchus platorynchus*) were represented in a single collection at the confluence of the Vermillion and Missouri rivers. In 1991, we found 41 species in the Vermillion River (Table 3), but we did not sample in the lower 10–12 km of the river or in many tributary streams. Excluding those six species found in a single collection from the confluence, six species (flathead chub, *Platygobio gracilis*; blacknose dace, *Rhinichthys atratulus*; silverstripe shiner, *Notropis stilbius*; river shiner, *Notropis blennius*; Mississippi silvery minnow, *Hybognathus nuchalis*; and yellow perch, *Perca flavescens*) were found by Underhill (1959) but were not collected in 1991. Blacknose dace have a limited distribution in the basin, and were only found in localized riffles in a tributary of Clay Creek in Time 1. These riffles were not sampled in Time 2. Since the flathead chub, silverstripe shiner, and Mississippi silvery minnow were found only at the mouth of the river in Time 1, lack of sampling effort at the mouth may have resulted in absence of these species during Time 2.

Four species (highfin carpsucker, *Carpiodes velifer*; golden shiner, *Notemigonus crysoleucas*; tadpole madtom, *Noturus gyrinus*; and white bass, *Morone chrysops*) were present in 1991 collections but were not found during the 1956–59 period. The white bass and golden shiner are recent invaders of the basin. Ten species, mostly sight-feeding piscivores, have invaded the basin since it was settled by Euro-Americans. They include the northern pike, yellow perch, walleye, common carp (*Cyprinus carpio*), golden shiner, white bass, largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and both crappie species (*Pomoxis* spp.; (Table 3). The only species in the basin which is of special concern is the plains topminnow. It is listed as threatened in South Dakota. This species was not sampled by Underhill (1959) or in the present study, but Kazmierski (1966) recorded it from Say Brook, a Clay Creek tributary. The current status of this species in the basin is not known.

Faunal Comparisons

Thirty-one fish species were collected from the eight sites during both periods. Twenty-three species were found in Time 1 and 30 species in Time 2 (Table 3). All species collected in Time 1 were also found in Time 2 except for bluegill and black crappie (*Pomoxis nigromaculatus*). However, both of these species were found in Time 2 at other sites not included in the analysis. Bluegill and black crappie occurred at only one of the eight sites sampled in Time 1. Eight species (stonecat; freshwater drum; goldeye, *Hiodon alosoides*; blue sucker, *Cycleptus elongatus*; walleye; white bass; shortnose gar; largemouth bass) were unique to Time 2 collections. Of these species, only white bass were not collected at any of 27 locations sampled in Time 1.

Median statistical tests of species presence or absence between periods indicated there was no

Table 3. Fish species documented in the Vermillion River, South Dakota, during 1956–59 and 1991. XX denotes species collected from the eight comparative study sites and subsequently used in the analysis. X denotes species taken but not from eight comparative study sites. Scientific and common names approved by American Fisheries Society (1991).

Species	Common name	1956–59	1991
Ameiurus melas	Black bullhead	XX	XX
Anguilla rostrata	American eel	X[a]	
Aplodinotus grunniens	Fresh water drum	X	XX
Campostoma anomalum	Central stoneroller	XX	XX
Carpiodes carpio	River carpsucker	XX	XX
C. velifer	Highfin carpsucker	X	
Catostomus commersoni	White sucker	XX	XX
Culaea inconstans	Brook stickleback	X	X
Cycleptus elongatus	Blue sucker	X	XX
Cyprinella lutrensis	Red shiner	XX	XX
C. spiloptera	Spotfin shiner	XX	XX
Cyprinus carpio[b]	Common carp	XX	XX
Dorosoma cepedianum	Gizzard shad	XX	XX
Esox lucius[b]	Northern pike	X	X
Etheostoma exile	Iowa darter	X	X
E. nigrum	Johnny darter	XX	XX
Hiodon alosoides	Goldeye	X	XX
Hybognathus hankinsoni	Brassy minnow	XX	XX
H. nuchalis	Mississippi silvery minnow	X	
Ictalurus punctatus	Channel catfish	XX	XX
Icthyomyzon unicuspis	Silver lamprey	X[a]	
Ictiobus bubalus	Smallmouth buffalo	X	X
Lepisosteus osseus	Longnose gar	X	
L. platostomus	Shortnose gar	X	XX
Lepomis cyanellus	Green sunfish	XX	XX
L. humilis	Orange spotted sunfish	XX	XX
L. macrochirus[b]	Bluegill	XX	XX
Lota lota	Burbot	X[a]	
Luxilus cornutus	Common shiner	XX	XX
Micropterus salmoides[b]	Largemouth bass	X	XX
Morone chrysops[b]	White bass	XX	
Moxostoma macrolepidotum	Shorthead redhorse	XX	XX
Notemigonus crysoleucas[b]	Golden shiner	X	
Notropis atherinoides	Emerald shiner	X	X
N. blennius	River shiner	X	
N. dorsalis	Bigmouth shiner	XX	XX
N. stilbius	Silverstripe shiner	X	
N. stramineus	Sand shiner	XX	XX
N. topeka	Topeka shiner	XX	XX
Noturus flavus	Stonecat	X	XX
N. gyrinus	Tadpole madtom	X	
Perca flavescens[b]	Yellow perch	X	
Pimephales promelas	Fathead minnow	XX	XX
Platygobio gracilis	Flathead chub	X	
Polyodon spathula	Paddlefish	X[a]	
Pomoxis annularis[b]	White crappie	XX	XX
P. nigromaculatus[b]	Black crappie	XX	X
Pylodictus olivaris	Flathead catfish	X	X
Rhinichthys atratulus	Blacknose dace	X	
Scaphirhyncus platyorynchus	Shovelnose sturgeon	X	
Semotilus atromaculatus	Creek chub	XX	XX
Stizostedion canadense	Sauger	X	X
S. vitreum[b]	Walleye	X	XX

[a] Not collected during 1956–59 but included in faunal list.
[b] Introduced.

difference ($P > 0.05$) in the number of sites where lithophil species occurred. Within the lithophil guild, seven species were found more frequently in the 1956–59 collections than in 1991, whereas eight species were encountered more frequently in Time 2 collections (Fig. 2). Of the 16 lithophil species, only the occurrence of the shorthead redhorse, *Moxostomra macrolepidotum*, was significantly different ($P \leq 0.05$), being more frequent in the 1991 samples. As a group, phytophil occurrence was not different ($P = 0.11$) between periods. However, two species (largemouth bass and spotfin shiner, *Cyprinella spiloptera*) were found at significantly more ($P \leq 0.05$) stations in 1991 than during 1956–59 (Fig. 2). Of the miscellaneous guilds, only the number of collections containing stonecats was statistically different ($P = 0.009$) between periods (Fig. 2). Stonecats were more frequently sampled in the 1991 samples.

Discussion

Comparisons of the Vermillion River fish community between 1956–59 and 1991 collections indicate that few, if any, changes in species composition have occurred. Although some species (i.e., shorthead redhorse, spotfin shiner, largemouth bass, stonecat) were encountered more frequently in recent collections, one would expect that all members of their respective guilds would respond similarly if spawning habitat had changed over the 35-year period. In this study, about 50% of the lithophils were encountered more frequently in 1991, whereas the others were present at more sites during 1956–59. Because species in all guilds are maintaining their presence in the river, suitable habitat for reproduction seems to be present. Assuming collections from both periods accurately depicted the fish communities, no detectable changes have occurred in the Vermillion River basin. Thus, the present fish community is stable and represents the historic (post 1955) Vermillion River fish community. Seemingly, watershed alterations have had little effect on species deletions or additions. In all probability the densities of some species have changed, but we were unable to assess these changes because no density data were taken during Time 1.

Based on the only previous historical distribution of fish in the Vermillion River (Underhill 1959), certain species now seem to be more widely distributed in the basin. Goldeyes, blue suckers, and flathead catfish were reported only near the mouth of the Vermillion, but in the present study goldeye were found 30 km upstream, blue suckers 10 km upstream, and flathead catfish 25 km upstream. White bass, not previously recorded in the Vermillion River, were found only at our most downstream stations.

The new distributions of these species in the Vermillion River may be linked more to modifications of the Missouri River than the Vermillion River. Moreover, this may indicate that the Vermillion River has increased importance as a spawning and rearing location for large Missouri River fish. Blue suckers have declined in the Missouri River since the turn of the century (Pflieger 1975), and their decline is directly attributable to dam construction. This species is currently a candidate for inclusion on the federal endangered or threatened species list. The blue sucker is adapted to turbid, free-flowing river systems, a condition no longer present in most of the Missouri River. The present state of the Vermillion River may provide more suitable habitat than that provided by the modified Missouri River. Actually, tributary streams probably always have been important spawning areas for blue suckers and other species of the large river assemblage. In April 1966, Beal (1967) collected 130 blue suckers in breeding condition from the adjacent James River.

White bass were introduced and have become well established in the Missouri River, following dam and reservoir construction in the past decades. Dispersal of white bass into the Vermillion River indicates that this species is extending its range and may become a major sport fish in the basin. The white bass may utilize tributaries as spawning and rearing grounds, similar to the blue sucker.

Conclusion

What does the future hold for the Vermillion River? Given a relatively stable human population, similar land-use patterns, and no major climatic changes, we believe this prairie river will remain viable. Perhaps this stream's most important function will be its contributions to the community metabolism of the Missouri River. Over two-thirds of the Missouri River mainstem is currently channelized or impounded. Populations of riverine fish species common to the unmodified Missouri River have been decimated in the last 4

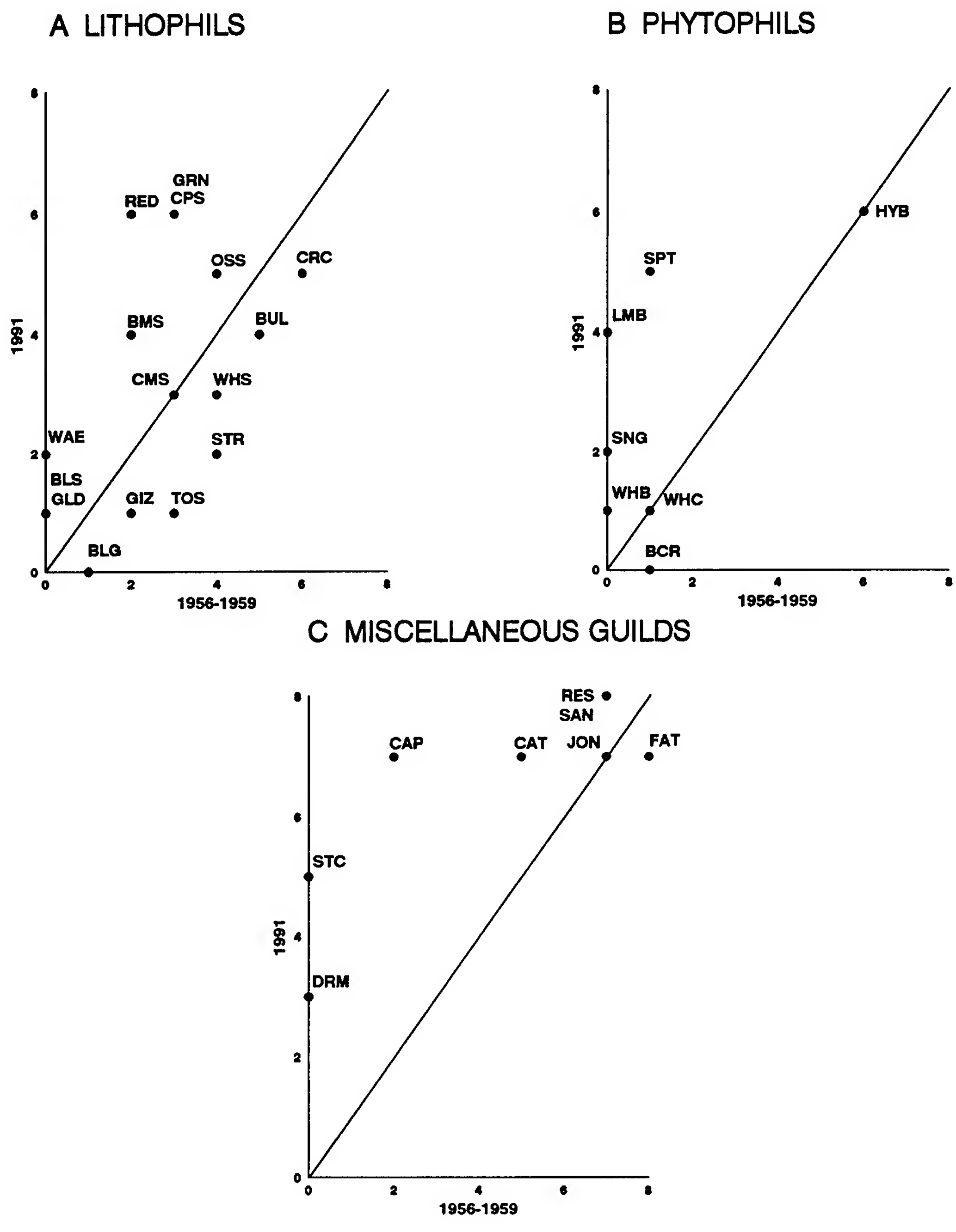

Fig. 2. Number of sites at which fish species were collected in the Vermillion River during 1956–59 and 1991. *Vertical line* depicts equal occurrence between both study periods (BMS = bigmouth shiner, BUL = black bullhead, BCR = black crappie, BLG = bluegill, BLS = blue sucker, CAP = common carp, CPS = river carpsucker, CAT = channel catfish, CMS = common shiner, CRC = creek chub, DRM = freshwater drum, FAT = fathead minnow, GIZ = gizzard shad, GLD = goldeye, GRN = green sunfish, HYB = *Hybognathus* spp., JON = Johnny darter, LMB = largemouth bass, OSS = orangespotted sunfish, RED = shorthead redhorse, RES = red shiner, SNG = shortnose gar, SPT = spotfin shiner, STC = stonecat, STR = central stoneroller, TOS = Topeka shiner, WAE = walleye, WHB = whitebass, WHC = white crappie, and WHS = white sucker).

decades. Changes in fish habitats have resulted from flood control and navigational developments. Stabilized flows in the downstream one-third of the Missouri River have confined the river to a uniformly deep channel. Suspended sediments have declined 80% at Omaha and 67% at St. Joseph (Slizeski et al. 1982). Much of the allochthonous organic carbon and nutrients derived from the floodplain is denied aquatic organisms in the lotic ecosystem. Turbidity levels have been lowered, favoring sight-feeding species. Backwater areas and chutes that formerly functioned as feeding, spawning, and rearing sites for riverine species have been largely destroyed or separated from the mainstem. More than ever before, the well being of the Missouri River fish and fisheries is dependent on small, stable tributaries like the Vermillion River. Despite its name, the Vermillion River is never red and it is far from dead. The Vermillion River is a viable ecosystem and a small but essential component of the Missouri River system.

Acknowledgments

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The James River of The Dakotas

by

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Abstract. The James River in North Dakota and South Dakota is a turbid, warmwater river that has (1) extreme variation in seasonal flows, (2) an intermittent upper mainstem, (3) great wildlife value, (4) an agriculturally dominated watershed, (5) high productivity, and (6) a large number of low-head dams (230). The river may be changed by proposed water development projects that would add irrigation water, control flooding, and augment flow during low-flow periods. Much is known about the physical, chemical, and biological aspects of the river because of studies on the potential effects of the proposed projects. The fish community has changed little over 100 years. High quality, in-stream habitat for the 57 fish species is sparse. Riverine reaches dominated by complex habitat features such as snags, rocky areas, low-head dams, and tributaries have higher densities of adult fishes than do areas of simpler habitat. Recreational use of the river is diverse; fishing exceeds 140,000 h annually. Bullhead (*Ameiurus* spp.), northern pike (*Esox lucius*), and channel catfish (*Ictalurus punctatus*) are the most-caught game fishes. A chief stressor is low dissolved oxygen, which is usually

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associated with low flows and which causes fish kills. Other factors affecting the fishery are low-head dams, hypereutrophy, turbidity, and high summer temperatures. Fishes from the Missouri River inhabit the lower portions of the James River, and larvae of about 15 species drift from the James into the Missouri. Neither state has specific management programs for the river, but both have stocked nonnative game fish into the mainstem and impoundments on tributaries. Research is needed on fish ecology, particularly migratory behavior, and on fish habitat improvement methods. Biomonitoring should be implemented to develop baseline data to document effects of proposed river improvement projects.

The James River presents challenges to fish and man because of its extreme variation in flow. The river has been called a "meandered lake" because of its low gradient and discharge. Low flow sometimes causes poor water quality. Boosting flows with stored water has been proposed to improve water quality and fish habitat (U.S. Army Corps of Engineers 1992). Conversely, spring runoff causes flooding that has prompted channel clearing programs, mostly snag removal. In the future, discharge may increase if water from irrigation projects enters the basin. Three federal wildlife refuges on the river attest to its importance to wildlife, and require that both fish and wildlife values be considered when planning river management. Agriculture dominates the watershed, and farming practices have added silt, nutrients, and low-head dams. Several comprehensive reports include information about the river (U.S. Department of Agriculture 1966; Benson 1983; South Dakota Department of Water and Natural Resources 1987, 1990; U.S. Geological Survey 1988; U.S. Army Corps of Engineers 1989, 1992).

The objectives of this report are to review the history and current status of aquatic resources of the James River and discuss factors that may affect the fish community.

Characteristics of the System

The James River flows 760 km through southeastern North Dakota and eastern South Dakota and empties into the Missouri River near Yankton (Fig. 1). The James River is a typical warmwater stream with substantial flow and temperature variation, shallow channels with uniform sandy beds, and turbid waters (Winger 1980; Cross and Moss 1987). This sinuous river has one of the lowest gradients of any river of similar length in North America. The riverine fish community is dominated by the catfish–carp–carpsucker community that Funk (1970) described as typical of prairie rivers (Table 1). Stocked fish such as common carp, black crappie, white crappie, largemouth bass, and various sunfish inhabit numerous small mainstem impoundments, where lacustrine conditions foster biotic communities that resemble those in surrounding lakes.

Distinctive River Regions

The 57,000-km^2 basin comprises glacial material from four ice advances over Precambrian quartzites and Cretaceous chalks and shales. Hence, the river water has relatively high pH, alkalinity, hardness, and dissolved solids (Fig. 2). Two major physiographic regions covered by the river are the Drift Prairie region in North Dakota and the Central Lowland region in South Dakota.

Four river reaches are recognized by their distinctive flow characteristics, fish communities, and other ecological features. The first reach is the headwater reach in North Dakota, where the slope is 46 cm/km; the river is incised into glacial drift and is intermittent. The second reach is referred to as the lake plain because glacial Lake Dakota once covered this 250-km reach. Here, the gradient is as low as 2.4 cm/km. The channel is not well defined and has a sinuosity of 2.2. This reach is dominated by hardwood timber, wetlands, and oxbows. The second reach has been nominated for Scenic and Recreational River status (South Dakota Game, Fish, and Park 1976; Vandel 1986), and it has also received the most attention because of sediment aggradation and flooding. The third reach is near Huron, South Dakota. This reach is relatively straight (sinuosity = 1.4) and has a greater channel capacity and narrower floodplain than the other reaches. The fourth reach is from Huron to the Missouri River, where meanders increase once again, and the river drops about 12 cm/km.

Fig. 1. Map of the James River watershed in North Dakota and South Dakota.

Climate and Flow

Climate in the basin is classified as subhumid continental; warm summers, cold winters, and wide daily and day-to-day temperature extremes occur. Periods of drought and excessive precipitation are common. Average annual precipitation ranges from 45 cm in North Dakota to 56 cm in South Dakota. Average discharge over 63 years is 11.8 m^3/s (range = 0 - 832 m^3/s), and average water yield is 373.5 million m^3/year (Burr et al. 1991).

Most runoff occurs from March to July and is 50–75% snowmelt (Fig. 2). Flood hydrographs in South Dakota tend to have moderately rising front limbs, broad peaks, and very slowly descending and prolonged recession limbs. The Jamestown Dam alters the hydrograph in North Dakota by reducing the peaks. Overbank flooding occurs along the entire river at least once every 10 years, once every 2 years in the upper river. About 8,505 ha of land in northern South Dakota are inundated in a 2-year flood, about 17,401 ha in a 5-year flood.

Zero-flow periods may last 130 days in the upper watershed (about half in winter), and only 7 days (most in fall) in the lower watershed. There are about 214 days when flow is less than 0.56 m^3/s in the headwaters, 85 m^3/s near the mouth. Most tributaries to the river are small and intermittent.

River Physical Features

The riverine fish habitat is sparse and has been termed "ecologically uniform" and "monotonous" (Fausch et al. 1984).

Macrohabitat features (e.g., snags, rocky outcrops, tributary confluences) dominate less than 5% of the James River. Walsh (1992) boated 190 km of the middle river (Stratford to Huron) and found rocky substrates in 3.8% of the reach; snags influenced 1%, and low-head dams and tributary confluences influenced about 0.1%. Berry (unpublished data) found 12 places (totalling 465 m in length) in a 24 km reach just above Olivet, South Dakota, where the stream bottom was dominated by cobble-to-bolder habitat. He also counted 133 complex snags (three or more trees) in the reach and about 600 snags of lesser complexity.

The channel bed in North Dakota is mostly coarse sediments, whereas in the middle and lower reaches silt and sand are common. In general,

Table 1. Abundance and location of fish found in the James River. Dates shown indicate last report; otherwise the species has been collected since 1975 (Frederickson and Houtcooper 1986; Kubeny 1992; Van Eeckhout and Steinwand 1992; Walsh 1992).

Family Scientific name	Common name	Abundance and location[a]
Acipenseridae		
Scaphirhynchus platorynchus	Shovelnose sturgeon	S
Polyodontidae		
Polyodon spathula	Paddlefish	S
Lepisosteidae		
Lepisosteus platostomus	Shortnose gar	S
L. osseus	Longnose gar	S
Anguillidae		
Anguilla rostrata	American eel	S
Clupeidae		
Dorosoma cepedianum	Gizzard shad	N,S
Hiodontidae		
Hiodon alosoides	Goldeye	N,S
Esocidae		
Esox lucius	Northern pike	N,S
Cyprinidae		
Campostoma anomalum	Central stoneroller	S
Cyprinella lutrensis	Red shiner	S
Cyprinus carpio	Common carp	N,S
Hybognathus hankinsoni	Brassy minnow	1962,S
H. nuchalis	Mississippi silvery minnow	1929,N
Luxilus cornutus	Common shiner	N
Nocomis biguttatus	Hornyhead chub	1929,N
Notemigonus crysoleucas	Golden shiner	N
Notropis atherinoides	Emerald shiner	S
N. dorsalis	Bigmouth shiner	S
N. heterolepis	Blacknose shiner	1896,S
N. hudsonius	Spottail shiner	S
N. stramineus	Sand shiner	N,S
N. topeka	Topeka shiner	S
Pimephales notatus	Bluntnose minnow	1892,N
P. promelas	Fathead minnow	N,S
Rhinichthys atratulus	Blacknose dace	N,S
Semotilus atromaculatus	Creek chub	N,S
Catostomidae		
Carpiodes carpio	River carpsucker	S
Catostomus commersoni	White sucker	N,S
Cycleptus elongatus	Blue sucker	S
Ictiobus bubalus	Smallmouth buffalo	S
I. cyprinellus	Bigmouth buffalo	N,S
Moxostoma macrolepidotum	Shorthead redhorse	N,S
M. erythrurum	Golden redhorse	S[b]
Ictaluridae		
Ameiurus melas	Black bullhead	N,S
A. natalis	Yellow bullhead	S
A. nebulosus	Brown bullhead	1896,N
Ictalurus furcatus	Blue catfish	S
I. punctatus	Channel catfish	N,S
Noturus gyrinus	Tadpole madtom	N,S
Pylodictis olivaris	Flathead catfish	S
Cyprinodontidae		
Fundulus sciadicus	Plains topminnow	S

Table 1. *Continued.*

Family Scientific name	Common name	Abundance and location
Gasterosteidae		
Culaea inconstans	Brook stickleback	N
Percichthyidae		
Morone chrysops	White bass	S
Centrarchidae		
Lepomis cyanellus	Green sunfish	S
L. humilis	Orangespotted sunfish	N,S
L. macrochirus	Bluegill	S
Micropterus dolomieu	Smallmouth bass	N,S
M. salmoides	Largemouth bass	N,S
Pomoxis annularis	White crappie	N,S
P. nigromaculatus	Black crappie	N,S
Percidae		
Etheostoma exile	Iowa darter	N
E. nigrum	Johnny darter	N,S
Perca flavescens	Yellow perch	N,S
Percina maculata	Blackside darter	1896,N[c]
Stizostedion canadense	Sauger	N[d]
S. vitreum	Walleye	N,S
Sciaenidae		
Aplodinotus grunniens	Freshwater drum	S

[a]N = collcted in North Dakota; S = collected in South Dakota.
[b]One specimen collected in 1980's.
[c]One specimen only.
[d]Stocked in Jamestown Reservoir (North Dakota), but not collected in the James River.

sediment averaged about 1 m deep in the lake plain and decreased downstream (U.S. Bureau of Reclamation 1988). At peak discharge, sediment volume is 400 metric tons/day midriver and 2,529/day at the mouth. Soil loss of about 3.65 m^3/ha (U.S. Department of Agriculture 1966) is low because of the flat, nonintegrated drainage area, low tributary gradients (0.4–1.2 m/km), permeable soils, and low frequency of runoff events. These factors also contribute to a low rate of sediment transport (U.S. Bureau of Reclamation 1988).

Banks are not usually exposed to hydraulic conditions that result in bank erosion, except during floods. Several studies have been conducted to predict effects of increased summer flows from irrigation on bank erosion (U.S. Bureau of Reclamation 1988; U.S. Army Corps of Engineers 1989). The river was found relatively stable with few erosion sites. The maximum rate of migration at erosion sites averaged 0.33 m/year. The lower 8.6 km of the river has the highest erosion potential because of Missouri River influences (U.S. Army Corps of Engineers 1989).

Developments

Explorers in the 1800's described the James River valley as "great stretches of level prairie . . . presenting a smooth surface without one sprig of grass higher than the other . . . unbroken except by the many herds of buffalo." They described the river as having a "scattered, wooded line" that twisted through the sea of grass.

Today, 50–65% of the basin is cropland (corn and wheat), which is increasing yearly, and pasture. Forests (2% of the basin) grow in narrow strips along the river as two woody plant communities—riparian and woodland (Choate and Spencer 1969). Of the 716 km of river border in South Dakota, 302 km (42%) are occupied by the riparian community, 72 km (10%) are occupied by the woodland community, and the remainder (48%) is not forested.

In eastern South Dakota, woodlands decreased from 192,375 ha in 1935 to 107,850 ha in 1980 (USFS 1981). Even though the woodland corridor is somewhat fragmented, it forms an important

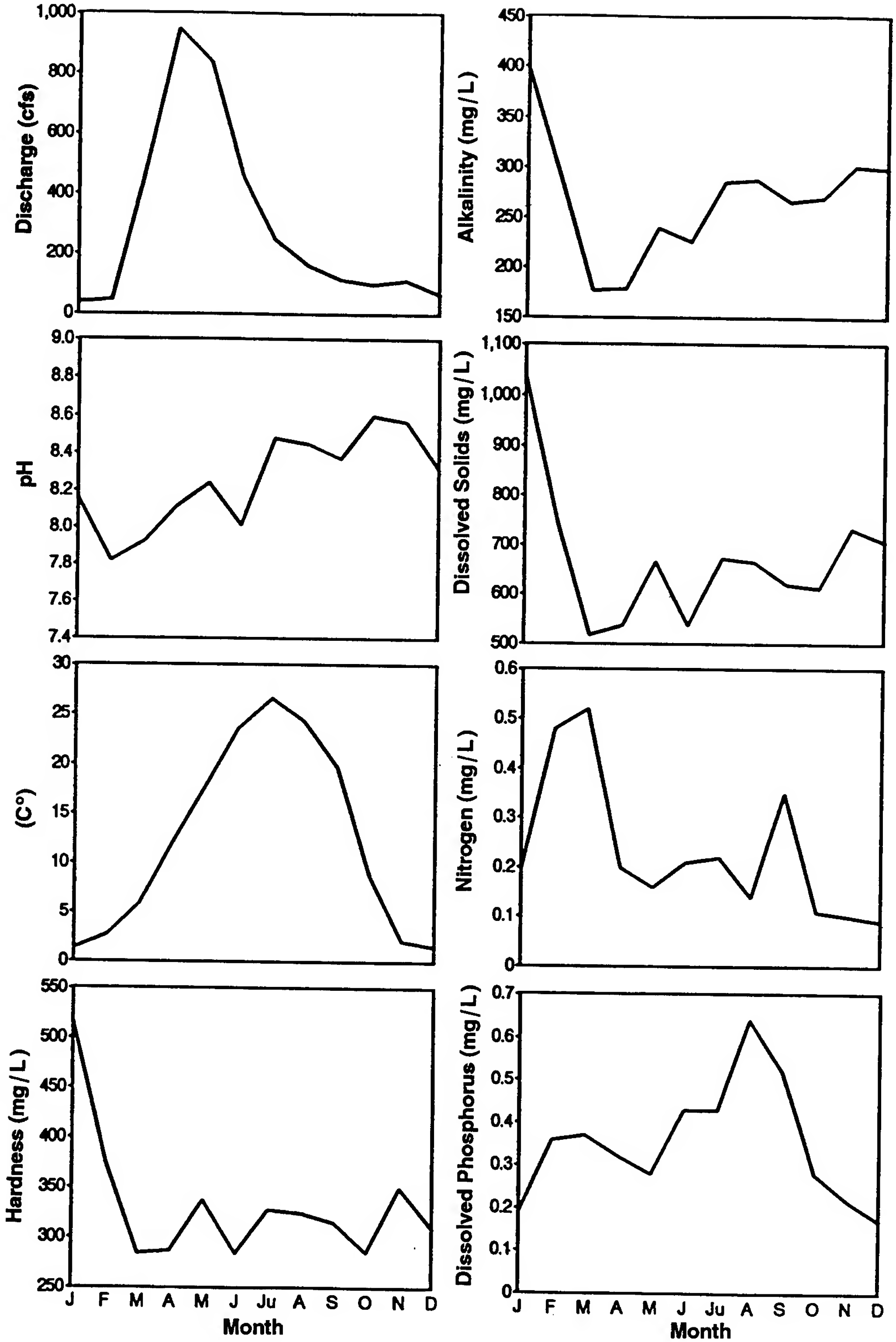

Fig. 2. Selected monthly water quality trends in the James River, North Dakota and South Dakota. Data are monthly means of STORET data for Station 06478500 near Scotland, South Dakota, 1980–90.

north–south corridor of bottomland hardwood habitat. Dutch elm disease has ostensibly affected the river by killing the once abundant American elms (*Ulmus americana*), which then fall into the river and retard flow. However, woody debris is often considered beneficial to fish and wildlife of the river (Schneider 1978; Walsh 1992).

About 250,000 people live in the watershed, 56% in rural areas. The largest towns on the river are Huron (population 13,000) and Jamestown (population 16,000). There are 100 bridges in the South Dakota portion of the river; many older ones obstruct or redirect flow. A 28-m-high dam forms Jamestown Reservoir in North Dakota (770 ha, mean depth = 4 m), and about 230 low-head dams or rock bridges (cattle crossings) also cross the river. The six highest dams (excluding Jamestown) are from 2 to 5 m high, but most are less than 1 m. All (except Jamestown) are usually submerged during spring floods (U.S. Army Corps of Engineers 1992). Total storage capacity, including national wildlife refuge waters, is about 46.8 million m^3.

Proposed Projects

Several proposed water development projects may change the hydraulic characteristics of the James River (Carrels 1987). Two irrigation projects, (CENDAK in South Dakota, Garrison in North Dakota) may someday deliver Missouri River water for irrigation, municipal use, and wildlife habitat. Canals would run from the Missouri River to the James River valley, about 160 km. Increased flows (7–15 m^3/s; U.S. Bureau of Reclamation 1989) could improve dissolved oxygen levels between September and March and might enhance fish survival. Some fish, especially those adapted to large rivers, could become established farther upstream than at present (Owen et al. 1981). On the other hand, water quality might be degraded, particularly from increased salinities, and bank erosion might increase (U.S. Bureau of Reclamation 1988; U.S. Fish and Wildlife Service 1989).

A James River Restoration Project in South Dakota is part of the Water Resources Development Act of 1986 (PL 99-662, Section 401B). The act authorizes impoundments and other features to alleviate flood damage and regulate flows. Cost-share programs are assisting local sponsors with the restoration program to control flooding by removing flow obstructions. Snagging and clearing, dam modification, and dredging have been tried.

Past plans by the U.S. Army Corps of Engineers have emphasized flood control; however, a recent plan, termed "an environmental initiative," sought solutions to water quality problems related to low flows. The plan suggested modifying mainstem dams and placing two new dams (144 million m^3 capacity) on tributaries (U.S. Army Corps of Engineers 1992). The water would be released to increase flow (minimum of 0.56 m^3/s) during fall and winter and improve water quality.

Flow

Early explorers thought that the entire river was navigable by canoe and that the lower river would float boats larger than canoes. Today, the river has been declared legally navigable to Jamestown. There is no commercial navigation, but this designation allows the U.S. Army Corps of Engineers to regulate dredging and filling, and it makes the states owners of the river bottom. River water belongs to the states but may be acquired by appropriation. About 0.56 m^3/s is appropriated in North Dakota, and more water is appropriated in South Dakota than is normally available, but less is used than appropriated (T. Olson, South Dakota Department of Game, Fish and Parks, Pierre, personal communication).

Water is withdrawn for irrigation in North Dakota and South Dakota (47.6 million m^3), and is also withdrawn for municipal and industrial use in South Dakota (9.2 million m^3), but not North Dakota (U.S. Army Corps of Engineers 1992). Water is impounded for flood control (3.9 million m^3), recreation (11 million m^3) and fish and wildlife (37 million m^3). Neither state requires that certain flows be maintained for fish; South Dakota does require that water be released from reservoirs for municipal use. Discharges below 0.56 m^3/s occur often, and at this flow, the entire river is a series of pools, especially in the upper river, where flow is less than 0.14 m^3/s from September to February (U.S. Army Corps of Engineers 1992). Flows less than 2.8 m^3/s occur about 70% of the time in the upper river (above Stratford, South Dakota), 64% of the time in midriver reaches, and 12% of the time near the terminus (below Huron).

Around 1900, springs played an important part in the hydrology of the river (Owen et al. 1981; U.S. Army Corps of Engineers 1992). Headwaters flowed through open prairie and were described as "clear and vegetation choked." Water temperature on 28 August 1892 at Jamestown was 16° C (Woolman 1896). However, in the 1920's, the same sites

were described as "turbid" with a bottom of "clay, sand, and gravel." In the Dakota Lake plain, the river was described as having a mud bottom that was difficult to cross (Owen et al. 1981). Around Huron, pools were from 1 to 3.1 m deep, the bottom was muddy, and crossing the river was said to be difficult. In the late 1930's, the river near Huron was "sluggish and of greatly varying flow" (McClaskey 1940).

Wetland drainage has undoubtedly altered flow regimes. From Mitchell to the mouth nearly all oxbows and depressions have been drained. Upstream, perhaps 40% of the depressional wetlands have been drained (Higgins 1977).

Water Quality

The James River can generally be described as a fertile, warmwater, turbid stream (Fig. 2). The water contains a relatively high amount of dissolved solids, and thus, alkalinity, and hardness are relatively high and pH is usually basic (>7.8).

Water quality generally supports designated uses, that is, warmwater semipermanent fish propagation (fish kill every 10 years) and limited contact recreation. In North Dakota, treatment of point source pollution (mostly municipal) since 1981 has improved water quality, but a water quality variance is allowed for chlorides and sulfates.

Water quality in South Dakota has improved in the last 20 years. In the mid-1970's, the river had "intermediate to significant" water quality problems (U.S. Environmental Protection Agency 1978). Phosphorous, nitrogen, and total dissolved solids exceeded water quality standards. In 1986, the entire lower half of the river was designated as "partially" supporting designated uses, whereas in 1990, only a 65-km reach in the midbasin was so designated (South Dakota Department of Water and Natural Resources 1990).

Although the watershed is dominated by agriculture, only minor amounts of pesticides (Aroclor, <0.1 ppb; DDT, <0.07 ppb; endrine, <0.1 ppb) and metals (mercury, <0.6 ppb) have been found in the water. Agricultural activity usually causes high nutrient conditions through soil erosion during runoff (Omernik 1977; Baker 1984). Total phosphorous and total inorganic nitrogen concentrations in the James River have two maxima (Fig. 2). One occurs when discharge is high in the spring; the second peak, during late summer, is sometimes found in lentic waters.

Few studies have been made of carbon sources to streams in grasslands and agriculturally developed prairie watersheds (Wetzel 1983, p. 671). The downstream sequencing of carbon sources may be like that of the Vermillion River (Illinois), which is also in an agriculturally dominated watershed (Wiley et al. 1990). In the Vermillion River, headwaters are autotrophic, whereas carbon inputs from tree and crop leaves farther downstream foster heterotrophy. The James River has been subjectively characterized as having a "broad autotrophic and heterotrophic food base" but data are available only for autochthonous primary production (U.S. Army Corps of Engineers 1992). Total organic carbon ranged from 13 to 20 mg/L at four river sites and three reservoir sites.

Longitudinal distribution of photosynthesis in the James River is mediated mostly by turbidity, and somewhat by shading. Transparency in summer and early fall can exceed 2 m at Jamestown, North Dakota, and Columbia, South Dakota, in the upper river, but is reduced to about 0.3 m in the lower river. Factors that facilitate biotic production are eutrophication, allochthonous carbon inputs, sluggish current, and silt and muck bottom.

A water quality problem that has existed for some time is lack of dissolved oxygen during low flow and under ice (U.S. Army Corps of Engineers 1992). Dissolved oxygen was less than 1.0 mg/L in January and February from above Jamestown to near Frankfort, South Dakota, in 1951 (U.S. Public Health Service 1952). Today, the oxygen standard of 5 mg/L is violated about 5% of the time in North Dakota and 20% of the time in the Lake Plain (U.S. Army Corps of Engineers 1992).

Coliform bacteria are an additional water quality problem. Fecal coliform levels below cities and below Sand Lake refuge are 2–6 times higher than upstream from these sites (upstream = 40–80/100 mL).

Wildlife

Three federal wildlife refuges were established in the 1930's to protect the wildlife values of the river and to create additional wetland habitat with low-head dams (Fig. 1). Because of the refuges and the north–south orientation of the James River, the valley is internationally important as a migration corridor for waterfowl. At least 172 species of birds regularly use the valley during migration periods. Oxbows and riverine reaches are also important to breeding waterfowl, which are found in densities of about 4 pairs/km in wet years and 1 pair/km in dry years (Larson 1990). In 1987 there were 40 rookeries (13 active) on the

James River (U.S. Fish and Wildlife Service 1987). Most were used by great blue herons (*Ardea herodias*), great egrets (*Casmerodius albus*), and double-crested cormorants (*Phalacrocorax auritus*). Eight of the 23 great blue heron rookeries in South Dakota are on the James River. The birds feed primarily in rivers and streams (Dowd and Flake 1985).

Operation of the refuges influences the fishery. Wildlife managers depend on winter kill to reduce populations of common carp and black bullheads. These species hamper the growth of submerged vegetation that is important to waterfowl. Irrigation return flows from the Garrison project might decrease winter kill. Proposals have been made to ameliorate the effects of the additional flows by passing water through or around the refuges (U.S. Fish and Wildlife Service 1989).

Recreational Use

Recreational use of the river includes some 31 activities (Hansen 1981). Camping (about 600,000 h annually) and fishing (140,000 h annually) were the most popular activities from 1975 to 1979. Catch rates in the late 1970's were 0.4–0.8 fish/hour. Most anglers were residents of the basin.

Public access limits angling in North Dakota. There are about 24 state-owned access points in South Dakota, but increased access is needed. Recent recreational improvements included a canoe trail, improved river access (one site), and acquisition of wildlife habitat.

Aquatic Biota

Streams of the Great Plains region are characterized by their ecological uniformity (Gilbert 1980) and a biota that is adaptable and has generalized requirements (Pflieger 1971). These generalities apply to the James River.

Plankton

Forty to 48 genera of phytoplankton have been found in the James River (U.S. Public Health Service 1952; Hansen and Repseys 1986); bluegreen algae became dominant in the mid-1980's. Green algae prevail in spring, bluegreen algae (e.g., *Microcystis*) in summer. Chlorophyll data, which have been collected on an irregular basis, vary with river mile and season. Near Stratford, chlorophyll *a* values range from 6.7 to 64.9 µg/L, depending on season (South Dakota Department of Water and Natural Resources, Pierre, unpublished data). The river would be classified as eutrophic if Dobson's (1981) lake productivity index were used. The nature of the zooplankton community supports this classification because zooplankton are abundant and typical of communities found in nearby eutrophic lakes (U.S. Public Health Service 1952; Tol 1976; Hansen and Repsys 1986).

Macroinvertebrates

Macroinvertebrates have been inventoried (U.S. Public Health Service 1952; Tol 1976; Hansen and Repsys 1986), and their distribution has been related to macrohabitat features in the James River (Larson 1990; Schumacher 1992). Macroinvertebrate diversity and abundance was greater in oxbows than in the mainstem and was dominated by hemipterans, ephemeropterans, and odonates (Larson 1990). Chironomids and oligochaetes dominated benthic fauna in the mainstem (U.S. Public Health Service 1952), particularly in the Lake Plain (Hansen and Repsys 1986), but mayflies, odonates, beetles, and dipterans were also present. The mayfly *Hexagenia limbata*, which occurs where oxygen levels remain above about 1 mg/L, was abundant in 1984 but disappeared during winter 1985 (Hansen and Repsys 1986).

Schumacher (1992) collected invertebrates living on snags, mud bottoms, and rock bottoms in the middle James River. Taxa richness was higher on rocky substrates (62 genera) than on others (23–33 genera). Snags were dominated by chironomids (52,000/m^2), mud substrates by oligochaetes (12,000/m^2), and rocky substrates by mayflies (1,700/m^2). Caddisfly densities were higher in snag habitat (1,047/m^2) than in rocky substrates (171/m^2) or muddy substrates (17/m^2).

The clam community once comprised 17 species (possibly 19) representing 13 genera, but in 1985, *Anodonta grandis* was the most abundant of only four species (Perkins 1986). The fingernail clam (*Sphaerium* spp.), which prefers lentic conditions, was not found above Huron in the early 1950's, but was abundant in the Lake Plain in 1985 (U.S. Public Health Service 1952; Hansen and Repsys 1986). Several rare species of mussels may occur in the James River (Houtcooper et al. 1985).

Fish

In North Dakota early fish collections were made in the Jamestown and LaMoure area by Woolman (19 species, 1896) and Hankinson (23 species, 1929). Both biologists sampled two stations with seines. From 1983 to 1987 Van Eeckhout and Steinwand (1992) found 24 species (Table 1) by using a variety of gear at 27 sites representing various habitats.

In South Dakota, fish were collected at one site in the lower James River in 1892 by Evermann and Cox (1896), and Churchhill and Over (1933) reported species that are found in eastern tributaries of the Missouri River in South Dakota, but did not mention the James River specifically. Most studies are compared against that of Bailey and Allum (1962), who summarized systematic collections made by staff of the South Dakota Department of Game, Fish and Parks in the 1950's. They collected at three river sites less than 1.3 m deep, at one mill dam on the mainstem, at four tributaries, and at a site 16 km upstream from the Missouri River. They found 34 species in the watershed, of which three (largemouth bass, bluegill, pumpkinseed) were found only in lakes, five (northern pike, golden shiner, common shiner, tadpole madtom, bigmouth shiner) only in tributaries, and seven (gizzard shad, goldeye, emerald shiner, spottail shiner, smallmouth buffalo, channel catfish, freshwater drum) only near the Missouri River.

Since 1975, 10 biologists using a variety of gear (including piscicides) found from 22 to 41 fish species (57 total, Table 1; Russell 1975; Tol 1976; Elsen 1977; Fouberg 1980; Benda et al. 1981; Owen et al. 1981; Hansen 1984; Fredrickson and Houtcooper 1986; Kubeny 1992; Walsh 1992). Seven species are listed by North Dakota or South Dakota as species of concern (Table 2). Six unlisted species have not been collected recently in the James River, but are found elsewhere. No fish are listed as threatened or endangered by the Federal Government. Threadfin shad, gar, flathead catfish, freshwater drum, and goldeye are becoming more abundant in the upper river than in the past (Van Eeckhout and Steinwand 1992).

Bullheads usually dominate catches in nets and by anglers, who also catch northern pike, freshwater drum, and channel catfish. Catch in nets is more diverse downstream (Frederickson and Houtcooper 1986), as is angler catch (Table 3).

Fish surveys have also been made on tributaries (Bailey and Alum 1962; U.S. Fish and Wildlife Service 1986; Van Eeckhout and Steinwand 1992; Schumacher, unpublished data). More species were found in the mainstem than in tributaries. However, tributaries harbored species that prefer high velocities, gravel substrate, and clear water (i.e., central stoneroller, blackside darter, Topeka shiner).

Walsh (1992) reported the only fish biomass estimates. His seining between blocknets was 14–43% efficient, depending on habitat, so he expanded his biomass data with correction factors. Fish biomass (2-year mean) was about 1,190 kg/ha in complex habitats (areas of woody debris, low-head dams, tributary confluences, rocky bottom areas) and about 666 kg/ha in adjacent reaches with no in-stream habitat. These data are similar to those of Paragamian (1990), who found fish biomass was 300–1,200 kg/ha in most Iowa rivers.

Several nonnative species that are adapted to lacustrine situations have been introduced and have flourished. These include the white bass, common carp, black crappie, and white crappie. Common carp reached a biomass of about 2,000 kg/ha in wildlife refuge pools (Berry et al. 1990). Black crappie from refuge pools had an unusually high condition factor (Halseth and Willis 1989). Other introduced fish (largemouth bass, bluegill, smallmouth bass) are only found occasionally. Fishes stocked in the watershed but never found afterward include muskellunge (*Esox masquinongy*), rainbow trout (*Oncorhynchus mykiss*), pumpkinseed (*Lepomis gibbosus*), and grass carp (*Ctenopharyngodon idella*).

Species richness in the headwaters has been reduced more than that in other areas of the river. Five of 20 species collected by Woolman (1896) in North Dakota have not been collected recently, but only 1 species of the 20 found by Evermann and Cox (1896) in the lower river is missing from recent collections (Table 2). Species diversity (corrected Shannon index) and equitability (corrected Margalef's index) are higher in the lower river than in the upper (Frederickson and Houtcooper 1986). The number of species of darters, sunfishes, and suckers increases with stream order (Fausch et al. 1984).

Growth and condition (k factor) of six species (common carp, black bullhead, white crappie, black crappie, northern pike, and walleye) in the second reach of the river (Tol 1976) were similar to those of the faster growing populations of the same species listed by Carlander (1969). In another study in the same river reach, goldeye, walleye, and white crappie grew faster than similar populations in

Table 2. Fish listed as species of concern by North Dakota and South Dakota, and unlisted fish not collected recently in the James River.

Common name Scientific name	Status and comments
Listed by state	
Paddlefish *Polyodon spathula*	"Rumors" of occasional capture (Bailey and Allum 1962); Caught by angler (Hansen 1981)
Shovelnose sturgeon *Scaphirhynchus platorynchus*	Caught by angler (Hansen 1981)
Central stoneroller *Campostoma anomalum*	At three sites near Huron (South Dakota; Bailey and Allum 1962) and one site in 1975 (Owen et al. 1981)
Horneyhead chub *Nocomis biguttatus*	North Dakota only, not found since 1929 (Hankinson 1929)
Plains topminnow *Fundulus sciadicus*	One tributary in South Dakota (Owen et al. 1981)
Topeka shiner *Notropis topeka*	Two tributaries in South Dakota (Owen et al. 1981: Shoe Creek 1990, Schumacher, unpublished)
Blue sucker *Cycleptus elongatus*	Lower James River (Beal 1967)
Unlisted, not collected recently	
Brassy minnow *Hybognathus hankinsoni*	South Dakota in lake, two tributaries, and several main stem sites (Bailey and Allum 1962)
Mississippi silvery minnow *H. nuchalis*	North Dakota, in six other sites outside basin (Hankinson 1929)
Blackside darter *Percina maculata*	North Dakota, one specimen (Woolman 1896)
Blacknose shiner *Notropis heterolepis*	South Dakota (Everman and Cox 1986); prefers clear, vegetated waters
Brown Bullhead *Ameiurus nebulosus*	North Dakota (Woolman 1896); may be overlooked because of abundance of black bullheads
Bluntnose minnow *Pimephales notatus*	North Dakota (Woolman 1896); many small specimens taken

nearby lakes; northern pike, largemouth bass, and green sunfish grew slower; and yellow perch grew at about the same rate (Benda et al. 1981). Growth and population structure of channel catfish in the lower river were similar to those of channel catfish in other midwestern rivers (Kubeny 1992).

Factors Affecting the Fishery

Six factors are probably important influences on the James River fish community, besides ecological factors that affect all stream fish communities (reviewed by Heins and Matthews 1987).

Hydrology

The hydrology of the James River has changed with time. The operation of the Jamestown Dam has almost eliminated flooding to the state line (Fig. 1), but now silt is not deposited overland, and floods do not flush the river substrate. Smaller dams have created pools that are fish refuges during low flows but that also trap organic material and inhibit fish movement. For example, in 1975 and 1980 flow was nonexistent in parts of the upper river, and fish were concentrated behind dams (Benda et al. 1981).

A drop in the water table from irrigation pumping and wetland drainage has resulted in loss of water from springs. Some tributaries have become intermittent since settlement (Todd 1909). Low flow probably reduces reproductive success and nursery areas for juvenile fish (Schlosser 1982). For example, in April 1989 mean discharge near Redfield, South Dakota, was 54 m^3/s, whereas in April 1990 it was only 0.3 m^3/s. Consequently, the catch of juvenile fish in all macrohabitats was lower in 1990 than in 1989 (Walsh 1992). Low runoff may also reduce fish growth. For example,

Table 3. Percentage of dominant species (total number of species in parentheses) harvested by anglers from three sections of the James River, South Dakota, 1975–79 (Hansen 1981).

Species	River section Lower (19)	Middle (8)	Upper (4)
Bullhead *Ameiurus spp.*	27	71	72
Freshwater drum *Aplodinotus grunniens*	25	2	0
Channel catfish *Ictalurus punctatus*	24	<1	0
Northern pike *Exox lucius*	1	17	23
Other	23	9	5

growth of several fish (i.e., common carp, black bullhead, walleye) the summer after a high spring flow (1972, 1975) was greater than in years when flows were less (1971, 1973, 1974).

Macrohabitat

Fish-macrohabitat relations have been studied in the James River for yellow perch, northern pike, white crappie, and freshwater drum by using the Instream Flow Incremental Methodology (South Dakota Department of Water and Natural Resources 1985). Flow reduction from September to February limits habitat, degrades water quality, forces fish movement, and possibly limits recruitment because of winterkill. High spring water levels generally foster some spawning (in flooded vegetation), and successful year classes are possible.

Recent studies have compared fish use of macrohabitat features such as tributary confluences, rocky outcrops, and snag-dominated reaches with use of reaches without in-stream structure. Radio-tagged channel catfish used depths of about 1.1–2.1 m, velocities of less than 0.2 m/s, and sand and silt substrates; about 50% used complex log structures more often than simpler, smaller types of snag habitat (Kubeny 1992). Walsh (1992) found 1,760 adult fish/ha in complex habitats and 934 fish/ha in simple habitats (runs without instream structure). Density of juvenile fish was the same in complex and simple habitats.

Water Quality

Winterkills from low dissolved oxygen have been reported throughout the river. The kills are considered beneficial in the waterfowl refuges but harmful to recreational fishing in the river. Fish invade winterkill areas in spring, when flows improve access and dissolved oxygen levels. Catches of walleye are common during spring in the Lake Plain but not afterward. Oxygen depletions also occur in summer because of high temperatures and blooms of blue-green algae (Hansen and Repsys 1986).

Temperature extremes probably limit the success of coolwater fishes such as walleye and yellow perch. The upper river may reach 33° C when not flowing and then drop to 22° C during a summer storm. Average diurnal change is 8.3° C (South Dakota Department of Water and Natural Resources, unpublished data).

The upper river is eutrophic to hypertrophic. The lower river is perhaps mesotrophic. Chlorophyll *a* concentrations near Stratford fluctuated by season (higher in summer) but always indicated eutrophic conditions (>6.7 mg/L). Low light penetration may hamper productivity in some areas (U.S. Army Corps of Engineers 1992), and success of sight-feeding fish. However, growth of most fish species is similar to that in other rivers or nearby lakes (Tol 1976; Benda et al. 1981; Kubeny 1992).

Sediment accumulation in the upper river has negative effects on fish habitat. For example, fish pools dredged in the main channel were half-filled with sediment in 5 years (U.S. Army Corps of Engineers 1992).

Migration Barriers

The 28-m-high dam at Jamestown blocks fish migration and causes the river above and below the dam in North Dakota to function differently,

that is, intermittency above the dam and controlled flows below (Van Eeckhout and Steinwand 1992). Low-head dams are physical barriers to movement during low flows (about 60% of the year) because all dams lack fish ladders, but movement is rarely blocked because of high water velocity.

Hydraulic characteristics of low-head dams (1.3–5 m high) were assessed using HEC-2 models (U.S. Army Corps of Engineers 1992). Conditions considered included depth, velocity, water surface drop, dam design (many with stair-stepped weir crests), and backwater conditions. The models predicted velocity and elevation differences for 0.56 m^3/s and for 1-, 2-, and 5-year frequency flows. The surface drop at many dams became zero during 2-year flows (U.S. Army Corps of Engineers 1992).

We compared the average prolonged and burst-speed swimming ability of adult freshwater fish (30–60 cm/s, Beamish 1978) with predicted hydraulic conditions at 15 dams and speculated that three dams preclude migration, except during 5-year flows. For example, the James Diversion Dam, a 5-m-high concrete dam, is a barrier at less than 0.112 m^3/s and 1-year flows, but the 2-year flows pass down a grass-lined spillway and probably allow fish passage. On the other hand, a 1.3-m-high rock dam at Olivet with a stair-step weir crest is never a velocity barrier. Kubeny (1992) found that radio-tagged channel catfish moved downstream over this dam during high water. A 30-cm-long freshwater drum tagged in the Missouri River and recaptured below the Sand Lake Dam had moved past all dams in South Dakota.

Missouri River

A relation between the James and Missouri Rivers has been shown in several studies. Larvae of at least 15 species drift from the James River into the Missouri (Fouberg 1980; Muth and Schmulbach 1984). About 10% of 7,058 tagged channel catfish moved from the Missouri into the James River (Schainost 1981). Some moved 27 km/day and up to 402 km upriver. One of 12 channel catfish that were tagged in the James River emigrated to the Missouri River and was caught by an angler in the Platte River in Nebraska (Kubeny 1992).

Fish movement between the rivers may have increased since 1955, when Gavins Point Dam was closed. The dam, which is located about 15 km upstream from the confluence with the James River, may have altered water temperature or hydrologic regimes of the Missouri River, and the natural conditions still present in the James River may attract some species. Mainstem sites on the James River within 56 km of the Missouri River had greater species richness than other sites (Fausch et al. 1984). Gar, emerald shiner, smallmouth buffalo, white bass, blue sucker, and paddlefish, which are usually associated with the larger Missouri River, are found only in the lower James River.

Fisheries Management

Neither state has specific management plans for the river, other than the usual statewide creel limits, for example, 10 channel catfish per day in South Dakota. No fish habitat improvement projects are planned. The environmental effects of all proposed river development projects are reviewed by natural resource agencies of both states.

Fish populations have been augmented by stocking. Smallmouth bass fingerlings were stocked in the South Dakota portion of the river in 1989 and 1991; northern pike fry in 1989; walleye fry in 1985, 1986, and 1988; and walleye–sauger hybrids in 1985 and 1986. Northern pike, crappie, walleye, largemouth bass, yellow perch, and black bullhead have been stocked in the mainstem in North Dakota.

Removal of common carp upstream from the Jamestown Dam was attempted in 1953 but was unsuccessful. Common carp migrate upstream from Jamestown Reservoir to spawn in the marshes of the Arrowwood National Wildlife Refuge. Clark et al. (1991) captured 38–91 adult common carp (depending on month) per net night during summer 1988, but winterkill and low flow eliminated the population in refuge pools in 1989.

Research Recommendations

The tasks for warmwater stream biologists fall into three areas of research: life histories, populations dynamics, and environmental relations (Larimore 1981). The first and second concern community ecology, for which there are many areas of needed research (Hubbs 1987; Schoener 1987), particularly in prairie streams (see Zale et al. 1989 for a review). Research on environmental relations is important to the future of the James River because impact assessment is implied. Ecological research and impact assessment are complementary (Bain 1990).

The James River will be altered in the future, and the alterations might harm or help the fishery. Lower fish standing stocks were found at altered sites than at unaltered sites in Iowa streams (Paragamian 1990). Baseline data should be collected to help predict and evaluate effects of future projects. However, research is first needed on the value and applicability of various biomonitoring methods, such as rapid assessment techniques (reviewed by Plafkin et al. 1989), or more complicated fish production studies (Neves 1981).

Information is needed to determine the influence of low-head dams on fish movement for spawning or overwinter survival. The degree to which fish move is probably related to their size and reproductive habits, although the movement patterns of most stream fishes are poorly known (Moyle and Herbold 1987). This knowledge might also be used to locate and protect critical habitat.

Methods for habitat rehabilitation and protection need to be evaluated, particularly methods relating to stream bank and riparian zone protection (reviewed by Lyons and Courtney 1990), and woody debris management. The current perspective of riparian zone ecology (Gregory et al. 1991) may not apply to the narrow woody corridors through agricultural land, indicating the need for ecological research. Finally, snag removal programs continue to operate without clear definition. Research should be conducted to tailor such programs to benefit the fishery, including mitigation for snags that have been removed.

Conclusion

The Northern Plains is a region where, because so much depends on agricultural productivity, preservation of the landscape, rivers, and wetlands has not come first. Current agricultural practices and the importance of stabilizing the region's farm-based economy puts relentless pressure on natural resources such as the James River. The economic value of hunting and fishing, however, is being increasingly appreciated.

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Ecological Information and Habitat Rehabilitation on the Upper Mississippi River

by

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Abstract. Habitat rehabilitation is one of several alternatives available to a river management agency. Costs to rehabilitate even small areas of a system as large and complex as the Upper Mississippi River (UMR) are high. During the course of planning and implementing rehabilitation projects, certain pieces of critical information need to be identified and accessed. Items of information fall into four categories: system objectives and action levels, system status, causal factors, and evaluations of management alternatives. We use examples from the environmental and management history of UMR to demonstrate the roles of these pieces of information in the management process and especially how they relate to decision making for habitat rehabilitation. Few management plans have included measurable, ecologically based objectives and action levels, partly because of the difficulty of delineating the limits of the UMR ecosystem, the lack of useful ecological criteria, and fragmentation of management responsibilities. System status of the UMR is generally well known, but not in terms that can be quantitatively compared with objectives or action levels. The most difficult pieces of information to obtain fall in the category of causal factors. Information about causal factors is especially difficult to apply to projects on large rivers because of their dynamic nature, structural heterogeneity, and susceptibility to unpredictable interactions among many factors. Ongoing habitat rehabilitation projects on the UMR provide examples of the last information category. Most current projects address the problem of sedimentation. Two completed projects have shown different levels of success. Incomplete information about causal factors has been implicated in the lack of success of one project. Review of the critical information needed to take management action and acquisition of missing information will help increase the probability of success of future rehabilitation projects.

Habitat rehabilitation is one of several alternative actions that can be taken by managers to maintain an ecosystem within acceptable limits. On the Upper Mississippi River (UMR), habitat rehabilitation is a general term for any activity that is meant to improve ecological conditions for a specific population or community (for other definitions of rehabilitation and its relationship to restoration, preservation, and reclamation see U.S. National Research Council 1992). Substantial funding is necessary for the successful rehabilitation of even a small area within a large floodplain river ecosystem. The tasks of first justifying, designing, and building public and agency support for a project, and later constructing and evaluating it, require information that ranges from general to specific and from descriptive to predictive.

Rehabilitation efforts on the UMR began receiving increased funding in 1986 with the congressionally authorized Environmental Management Program (EMP). The EMP includes resource monitoring and research, and the design and construction of habitat rehabilitation projects are also contained in the EMP. The two program elements

are complementary parts of an iterative process of learning and informed action.

Trend analysis of selected resource components, research on causal factors and resource problems, and evaluations of biological responses to habitat projects are conducted under the Long Term Resource Monitoring Program (LTRMP). This program is implemented at the Environmental Management Technical Center, an office of the U.S. Fish and Wildlife Service, and a network of six field stations.

Habitat rehabilitation projects are identified and outlined by a sponsor, usually a state conservation department or a federal refuge office, ranked by a multiagency committee, and presented to the U.S. Army Corps of Engineers (Corps) for design and construction.

The EMP was initially planned to extend over 10 years at a cost of about $200 million. The large scale and cost of the program required the development of an unambiguous, product-oriented approach to the compilation and synthesis of information. The objectives of this paper are to highlight important features of the UMR ecosystem using a format that distinguishes different categories of information and to clarify the role and value of the categories in the rehabilitation process.

Categories of Information That Affect Habitat Rehabilitation Decisions

Four categories of information contribute to the river management process (Fig. 1). Following a framework established by Crowe (1983), the categories are system objectives and action levels, system status, causal factors, and evaluation of management alternatives.

Two types of decisions are made in this management process. The first is whether to take action. This decision is made at regular intervals

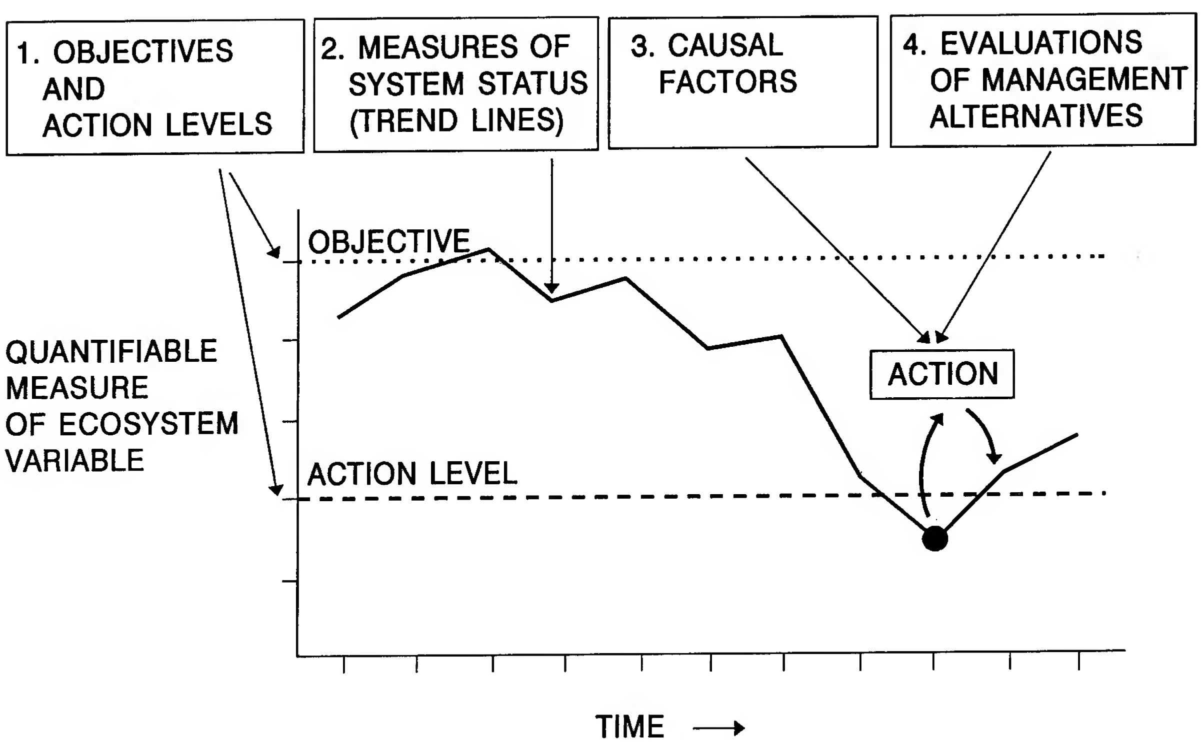

Fig. 1. Points at which categories of information fit into a river management process. No numbers were included on the vertical scale to emphasize that the units and the relative distance between objective and action levels are dependent on the quantitative variables used to measure ecosystem quality. For some variables, the position of objectives and action levels may be reversed.

and requires comparison of information from the first two categories. Action is triggered if the system, or one of its important components, passes a defined level. Decisions of the second type determine what action to take, where, and how. These decisions require an informed evaluation of the causal factors that resulted in the unacceptable status of the system and of what solutions are likely to remedy the problem in the most cost-effective way. Habitat rehabilitation is one management alternative.

Information in each category is vital; a lack of adequate information in any category can obstruct the process or reduce the chance for successful rehabilitation. Although each piece of information has greater value at a particular point in the process, data are often closely interrelated. For instance, almost all notable changes in the status of the system immediately stimulate analyses and speculations as to probable causes of the change. The management process is iterative; in practice, the supply of information is continuous as new studies are completed or observations are made.

To effectively contribute to the process, the pieces of information have to be coordinated. For instance, ecological variables and units of measure used to monitor system status should ideally be the same as, or convertible to, those used to establish objectives and action levels. Likewise, spatial and temporal scales used to monitor system status should also be suitable for identifying the scope and magnitude of resource problems and screening alternative solutions.

Discussion

System Objectives and Action Levels

Few attempts to establish measurable, ecologically oriented objectives and action levels related to the entire UMR have been made. More often, plans have been restricted to local management areas, directed at narrow taxonomic categories, or stopped short of defining measurable targets.

Some recent plans have made progress in these areas. The Master Management Plan for the Upper Mississippi River System (Upper Mississippi River Basin Commission 1982) covered the entire UMR and included economic, environmental, and recreational objectives. The objectives, however, were broad statements of intent, fitting more into Crowe's (1983) definition of goals. For example, the first environmental objective of the Master Management Plan was "to maintain and improve the quantity and quality of physical and biological resources which contribute to aquatic and terrestrial wildlife habitat." Although necessary for planning, this goal did not define a measurable target level of system status. Missouri's Big River Fisheries Ten-Year Strategic Plan (Missouri Department of Conservation 1991) and the North American Waterfowl Plan (U.S. Fish and Wildlife Service 1990) included target levels (for acreages of habitat restoration and waterfowl populations, respectively) as well as deadlines. But they were directed only at specific taxa.

Factors that have contributed to the lack of ecological objectives and action levels can be grouped under three subjects: problems of delineating appropriate space and time scales, the lack of applicable and documented ecological criteria, and fragmentation of management responsibilities.

Problems Delineating Space and Time Scales

The Upper Mississippi River has traditionally been defined as the aquatic and terrestrial habitats in the floodplain between Minneapolis, Minnesota, and Cairo, Illinois, a definition largely determined by historical jurisdictions of Corps offices. The boundaries of many fish and wildlife management areas along the UMR resulted from land purchases for construction of the lock and dam system (Rasmussen 1993).

Ecological boundaries, however, "are always, to a degree, arbitrary" (Rapport 1989). Functional ecological boundaries associated with a large floodplain river are usually indistinct, vary with time, and rarely align with management agency boundaries. The complex nature of fluvial systems necessitates consideration at several resolution levels (Amoros et al. 1987), and during development of a conceptual model of the UMR (Lubinski 1993), major factors and disturbances that affect the ecosystem were identified at five separate spatial scales: basin, stream network, floodplain reach, navigation pool, and habitat. Although the basin is the accepted land unit for studies of river ecology (Petts 1989), active natural resource management plans on the UMR are largely limited to the floodplain.

The basin and stream network scales in the LTRMP conceptual model extend beyond the traditional boundaries of the UMR. Management plans that cannot incorporate alternative actions at these scales are limited in their ability to address major

resource problems. The most notable current example on the UMR is sedimentation, a problem that originates at the basin scale. A common perception is that habitat projects on the floodplain that are designed to reduce local sedimentation rates or to rehabilitate areas affected by sediment may well be short-term "band-aids" that are limited in value when compared with the long-term and large-scale problem of sediment loading to the entire river.

Heterogeneity at the spatial scales of floodplain reach, navigation pool, and habitat adds to the difficulty of making ecologically based decisions. The three floodplain reaches of the UMR (Fig. 2) are structurally distinct in terms of their proportions of marsh habitat, water in nonchannel areas, and floodplain area levied for agriculture. Given these distinctions, needs for habitat rehabilitation in these reaches are quite different.

The dynamic temporal nature of a floodplain river creates problems in delineating useful decision-making time scales, as well as spatial scales. In the process of defining a disturbance, a reference period has to be identified (Resh et al. 1988; Sparks et al. 1990; Lubinski 1993). What, then, is the reference period for appropriate comparisons to present-day river development or habitat projects? Some ecologists would support management directed at returning the river to the ecosystem structure it had before European colonization. Many habitat projects on the UMR, however, are aimed at returning local areas to the conditions present immediately after impoundment. Because the post-impoundment period was unstable in terms of geomorphological equilibrium and because sedimentation in off-channel areas is part of the process of return to equilibrium, these projects could be viewed as small-scale battles in a long-term war that will become progressively more difficult and expensive to win.

Few rehabilitation projects, the Kissimmee River Project being a notable exception (Karr 1990), have included objectives that explicitly recognize the dynamic nature of floodplain rivers and the ecological benefits that can be derived from year-to-year variations in the annual hydrograph. Bayley (1991) noted that these benefits include the replenishment of bordering marshes and the scouring of stagnant backwaters, and listed the following among habitat management benefits associated with restoring the natural flood pulse: buffering of short-term water fluctuations, protection from excessive turbidity, reduction of pumping costs, fewer species management conflicts, and increased fish production in backwaters.

These benefits could be gained at several management scales. At the local level, one option might be to include enough spatial structure within a project to allow for the rotation of varying annual flood pulses among subareas, similar in practice to crop rotation on agricultural land. At a greater spatial scale, we need to acknowledge that "one in 500-year," channel-forming floods have functioned since the last glacial period to reset the ecosystem and maintain its vegetation in an early successional state (Sparks et al. 1990). It is infeasible to periodically recreate these events at any spatial scale, but substitute resetting actions could be included in a habitat project if one of its objectives is to maintain long-term floodplain vegetation composition.

Lack of Ecological Criteria

Ecological criteria are pieces of evidence that can be used to support objectives or action levels, much like water quality criteria are used by the U.S. Environmental Protection Agency to establish instream standards. The value of combining quantifiable metrics into indices of biological quality has been demonstrated for fish (Karr 1981), invertebrates (Ohio Environmental Protection Agency 1987), and habitats (Rankin 1989). However, ecological criteria that can be used to manage floodplain rivers are generally not identified.

Rapport (1989) listed seven symptoms characteristic of ecosystem breakdown: reduced primary productivity, loss of nutrients, loss of sensitive species, increased instability of populations, increased disease prevalence, changes in population structure to smaller life forms, and increased circulation of contaminants. An example based on primary production demonstrates how an ecological criterion already available could be used to support objectives and action levels. Primary production by aquatic macrophytes in the UMR is generally believed to be important for the maintenance of benthic invertebrates, fish, and migrating waterfowl, as well as for buffering shallow water habitats from wind action and preventing sediment resuspension and high turbidity levels. Yet, excessive densities of macrophytes have negative effects on fish communities. What, then, is an appropriate level of *Vallisneria americana* that benefits waterfowl as well as provides the other benefits listed above? Takekawa (1987) pro-

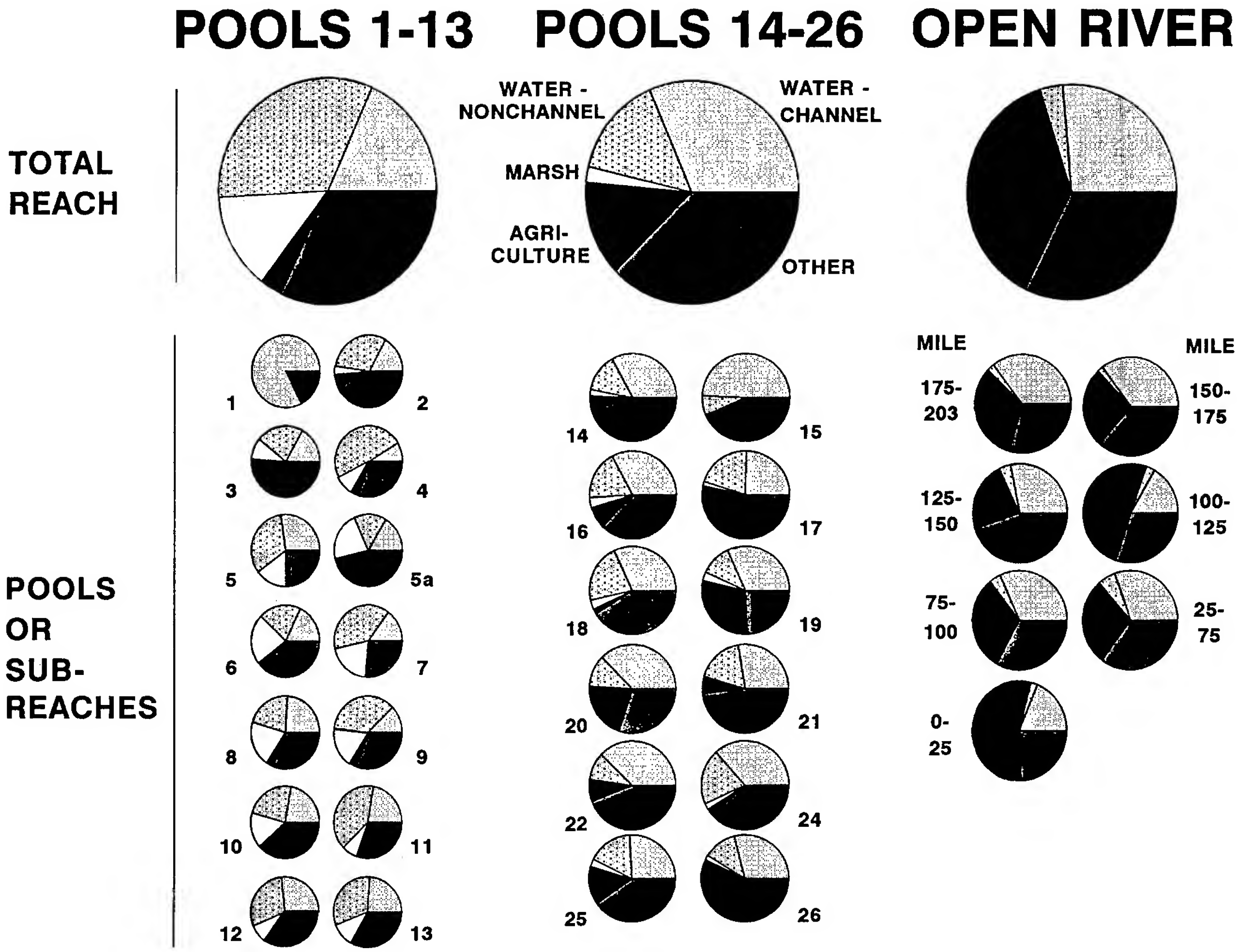

Fig. 2. Land cover classes of three floodplain river reaches, navigation pools, and segments of the open river. Data from a 1975 habitat inventory (Olson and Meyer 1976; Peck and Smart 1986). Marsh and nonchannel water habitats decline between the floodplain reaches bordered by navigation pools 1–13 and 14–26. Agricultural use of the floodplain increases in the floodplain reach bounded by pools 14–26 and is dominant along the open river.

vided an ecological criterion that answers part of this question by estimating that 25 tubers/m^2 of *V. americana* were necessary to maintain the net energy balance of a migrating canvasback. This value, in combination with others developed in relation to the benefits listed above, could stand as either an ecological objective or an action level for a defined area of the UMR.

For decision makers to readily accept ecological criteria, they must be confident that the criteria are applicable "in the field." Field observations that support the criteria are critical to promoting such confidence. But opportunities to observe specific and unambiguous causal relationships in the field may occur only infrequently. Therefore, benefits of long-term, standardized observations (monitoring) of major system components should include either progressively increasing confidence in established objectives or their modification.

Fragmentation of Management Responsibilities and Interest Groups

Measurable objectives or action levels are valueless unless a management agency has the responsibility, authority, and capability to take action. Fragmentation of environmental management responsibilities has been called one of the most serious problems of the Mississippi River (Craig and Anderson 1992). Holland-Bartels (1992) noted that for water quality alone, more than 17 federal agencies and 30 state departments or divisions have responsibilities and authorities on the UMR. Special interest groups add to the number of players that must be given a chance to

speak out on important management proposals. Given the improbability of major changes in agency authorities or reductions in interest groups in the near future, fragmentation will continue to require extra time and effort for the sole task of consensus building before any action can be taken.

Management problems caused by fragmentation are complicated by the multiple-use nature of the river. Congress formally embodied the multiple-use concept in the legislation (PL 99-662) that authorized the EMP and LTRMP, calling the river "a nationally significant ecosystem and a nationally significant commercial navigation system." Many current conflicts between federal and state agencies and river user groups can be traced back to the simple fact that these goals are frequently not compatible.

A multiagency alliance formed in 1942 has helped to remedy some of the problems that result from fragmentation. The Upper Mississippi River Conservation Committee (Committee), a coalition of fish and wildlife managers from Illinois, Iowa, Minnesota, Missouri, and Wisconsin, was formed "in a joint effort to better manage the common resource" (Keenlyne 1974). Observations of fishery changes, including winter mortality, caused by atypical water level fluctuations at navigation dams triggered the formation of the Committee. The Committee sponsored the river's first large-scale commercial and sport fish survey in the 1940's (Barnickol and Starrett 1951; Starrett and Barnickol 1955); holds annual meetings with indexed, published proceedings (Upper Mississippi River Conservation Committee 1988); published a compendium of fisheries information (Rasmussen 1979) and current distribution lists of fish species by navigation pool (Van Vooren 1983); and serves as a coordinating mechanism for multistate projects (Pitlo 1987; Janecek 1988).

The Committee recently proposed development of a "vision document" and associated strategic plans that would do for the natural resources of the UMR what Corps' planning documents will do for development of the commercial navigation system over the next 50 years. The proposed strategic plans could be the next step in progress to eventually establish the ecological objectives and action levels needed for the UMR.

In this section, we have addressed the value of ecologically oriented objectives and action levels to the rehabilitation of the UMR habitats. Well-founded objectives provide a second important service by providing scales for evaluating the magnitude and direction of changes in ecosystem attributes that result from human-induced disturbances.

System Status

A wealth of scientific publications, agency reports and environmental impact statements have described various ecological aspects of the UMR. Recent general descriptions include a volume on contaminant and sediment distribution, sedimentation rates, and impacts (Wiener et al. 1984); a collection of papers on its ecosystem components, processes, and disturbances (Smart et al. 1986); a description of the river's structure and fish fauna (Fremling et al. 1989); an evaluation of the relationship of water quality to its fishery resources (Holland-Bartels 1992); a conceptual model of the UMR and its disturbances (Lubinski 1992); and a history of management activities and conflicts (Rasmussen 1993). Since the 1960's, scientific studies have had an annual outlet for communication through the Mississippi River Research Consortium (Kapler 1973). Summaries of scientific investigations on the UMR are compiled annually by the Upper Mississippi River Conservation Committee (1991).

Information in the articles cited above provides a fairly comprehensive description of the UMR. We know, for instance, that

- The progressive navigation projects on the river, particularly the Nine-Foot Channel Project that created most of the locks and dams, resulted in dramatic changes in the geomorphology, sediment-trapping efficiency, low-discharge water levels, and aquatic vegetation of the river (U.S. Army Corps of Engineers 1978; Nielsen et al. 1984; Chen and Simons 1986; Peck and Smart 1986; Grubaugh and Anderson 1988; Grubaugh and Anderson 1989).
- These physical changes were not spatially uniform within navigation pools or among the three floodplain reaches of the UMR. Impoundment typically resulted in greater expansions of water area immediately above dams but little change in land-water boundaries in the upper reaches of pools. Much more marsh habitat was created in the floodplain reach bounded by pools 1 and 13 than in the

reach between pools 14 and 26 (Figs. 3 and 4).

- Sedimentation rates in depositional areas of the UMR are as high as 4.6 cm/year (Nielsen et al. 1984). Areas at greatest risk are the off-channel impounded areas created by the navigation dams.
- Species richness is declining from historical levels but at varying rates depending on the taxa in question. Mussel species in the UMR have declined from 48 to 37 species (R. E. Sparks, Illinois Natural History Survey, Havana, personal communication), whereas the number of fish species has remained relatively stable (Rasmussen 1979; Holland-Bartels 1992).

From the perspective of the management process, and especially for making habitat rehabilitation decisions, useful measures of system status need to be directly comparable to objectives or action levels and, whenever possible, accompanied by an estimate of the error associated with the measure.

A broad set of ecological variables that include important components, controlling factors, and perceived or real threats is usually necessary to monitor the integrity of an ecosystem. In the LTRMP (Lubinski 1992), resource components evaluated at regular intervals on the UMR include floodplain elevation, discharge and water elevation, water quality, aquatic and terrestrial vegetation, sediment composition, aquatic and floodplain habitat, macroinvertebrates, and fish (a strategy for monitoring wildlife is in preparation). Specific variables (e.g., catch per unit effort in the case of fishes) have been selected as measures of each component. In the absence of existing objectives and action levels, the components were selected "... to assess the physical, chemical and biological elements of the UMRS and to gauge their responses to natural and man-induced impacts" (Jackson et al. 1981).

In the LTRMP, monitoring data and data obtained from historical studies are used to ask the question "Is there a problem with a particular ecosystem component?" Perceived problems, such as recent declines in aquatic macrophytes, stimulate increased research. Thus, in an LTRMP research strategy, the term "problem" takes on a role analogous to an action level in the management process.

The monitoring data are also being collected to establish a baseline of quantitative measurements with which to estimate the statistical distributions of the selected variables under present-day conditions. Long-term data sets, collected using standardized methods and extensive quality control and assurance, will become primary evidence to support realistic UMR objectives and action levels.

Under the EMP, system status information is incorporated into decisions related to habitat rehabilitation at two levels. First, system status information is used to define the local habitat problem to be addressed. The problem and supportive information are described in a planning report for each proposed project. Second, broader system status information for the appropriate Corps district is reviewed during a multiagency project prioritization process. It is at this second level of system status review that the greatest gains in rehabilitation efficiency can be made. All proposed projects provide benefits to one or more system components. But comparing project values based only on conditions at the project site excludes the ability to evaluate the project as part of a greater whole. This gets back to the problems of appropriate space and time scales and defining the system that the project is meant to improve. However the system is defined, be it the entire UMR, a floodplain reach, or a specific navigation pool, the value of and need for a project must ultimately be established at the system level. Consequently, an evaluation of this type requires status information for the system, not just for the proposed project area. To meet this kind of informational need, a variety of historical and present-day maps of land cover, aquatic area classes, vegetation types, bathymetry, and topography are being produced within the LTRMP.

Causal Factors

A management action frequently cannot be predicted because it is partly dependent on the cause of the change and the opportunities available to return the ecosystem or its component to a desirable level. No information is more difficult to obtain than causal factors. Recent changes in UMR mussels (Blodgett and Sparks 1987; Thiel 1987), fingernail clams (Eckblad 1991; Eckblad and Lehtinen 1991), and aquatic macrophytes have prompted retrospective explanations.

Efforts to explain recent changes in aquatic macrophytes of the UMR exemplify some of the limitations associated with obtaining and using information about causal factors in habitat rehabilitation. Drought conditions occurred in the upper

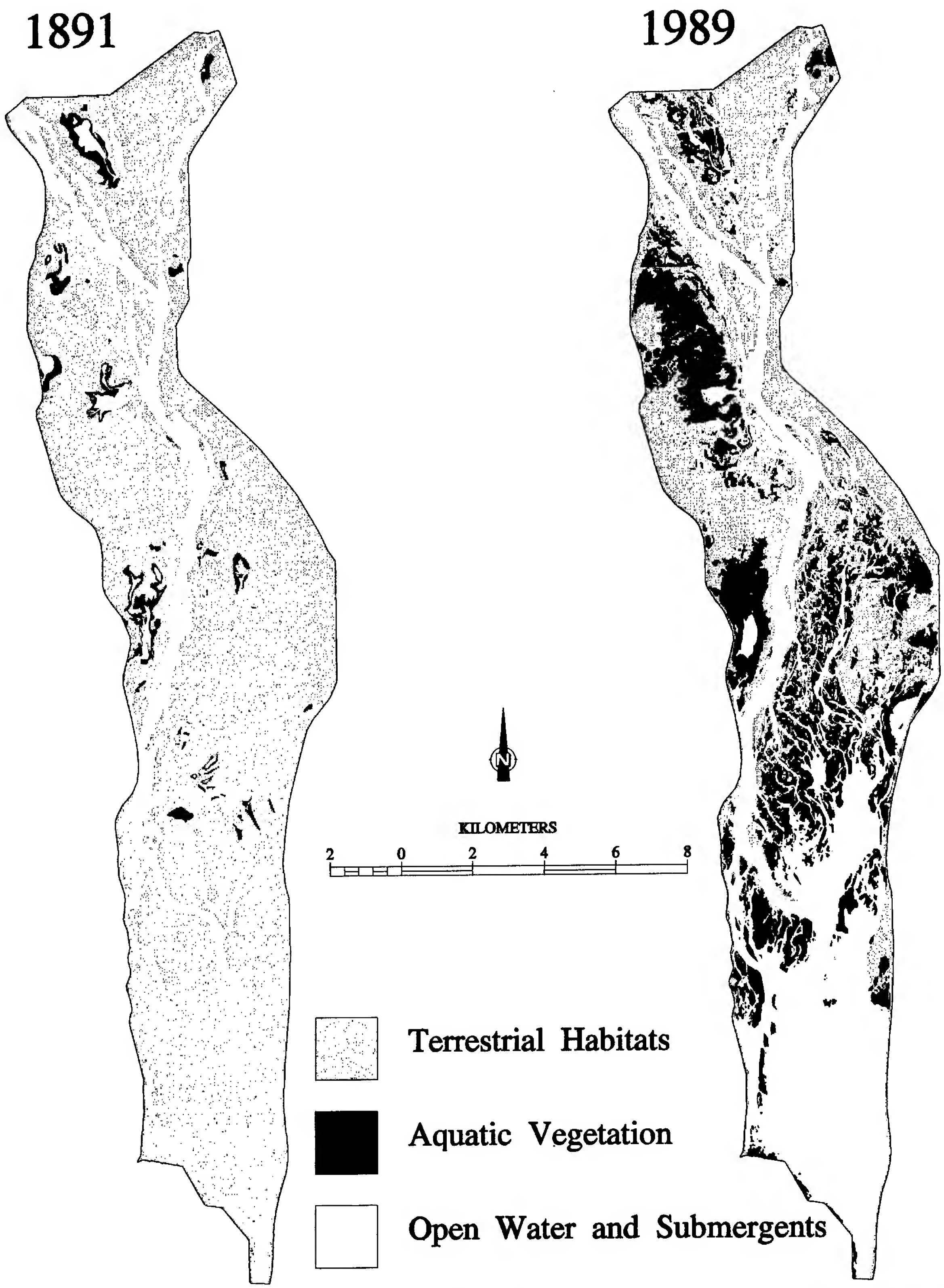

Fig. 3. Pre- and post-impoundment habitat changes in Navigation Pool 8. Impoundment created extensive open water and marsh habitats in previous floodplain forest areas.

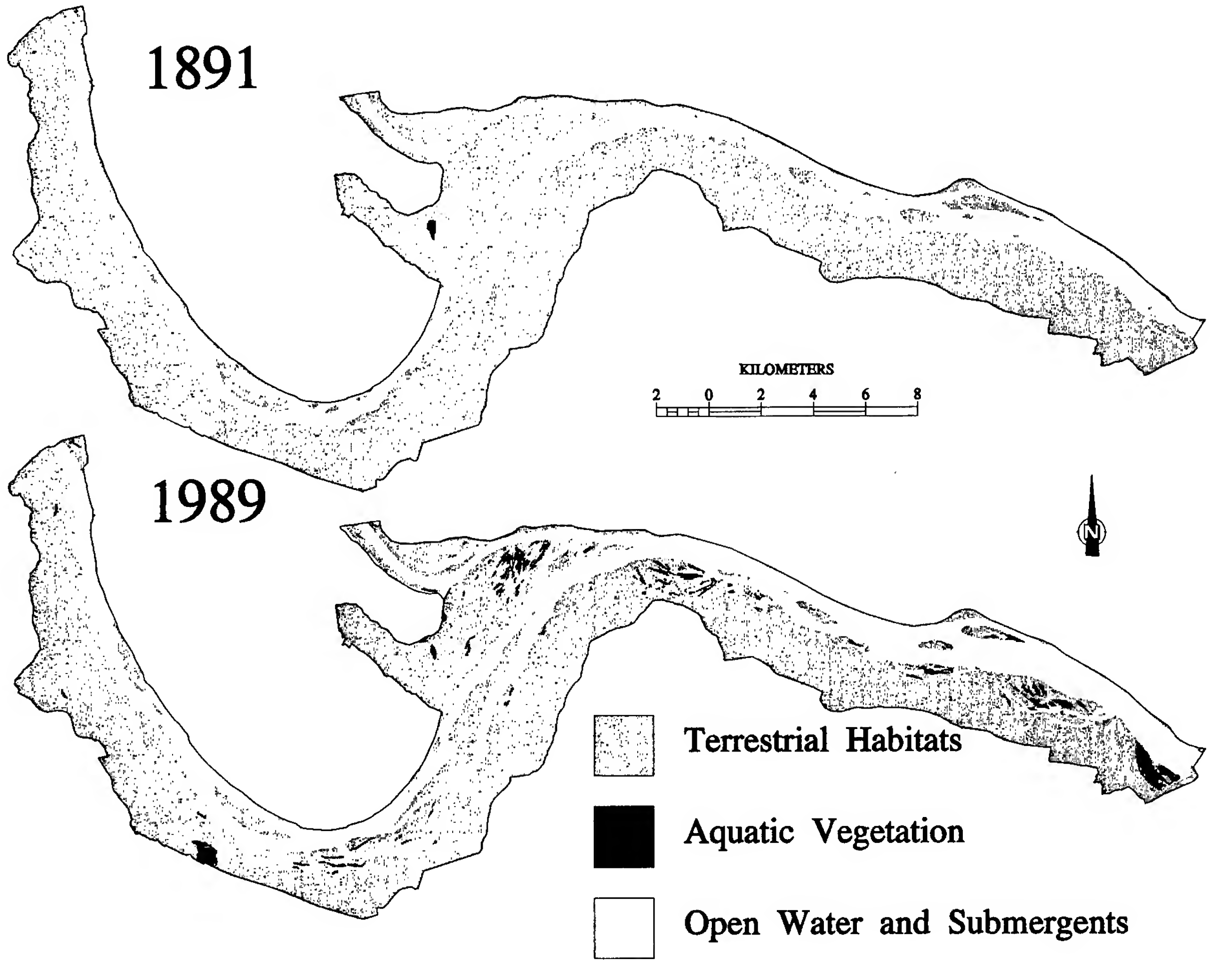

Fig. 4. Pre- and post-impoundment habitat changes in Navigation Pool 26. Impoundment resulted in relatively small increases in open water and marsh habitats (mostly limited to the lower Illinois River), partly because the floodplain had already been extensively levied for agricultural use.

Midwest in 1988 and 1989, resulting in relatively low river discharges and suspended sediment concentrations. Production of submersed aquatic macrophytes in navigation pools 7 and 8 was high in the summer of 1988, presumably in response to greater than normal levels of light. In 1989, despite similar drought conditions, production dropped low enough for wildlife managers to be concerned that there would not be enough overwintering tubers of *V. americana* to support migrating canvasbacks. To document the problem and propose the most reasonable explanation, river biologists met and compared observations. Possible contributing factors were discussed, including nutrient enrichment, anoxia, water temperature, solar radiation, runoff, ice, phytoplankton–periphyton, suspended solids, water levels, flow–discharge, waterfowl grazing, and agricultural chemicals. Limited water quality data available for the affected area supported a hypothesis that low flows and increased concentrations of water column nutrients in the first drought year promoted the growth of periphyton on *V. americana* and reduced macrophyte photosynthesis when overwintering tubers were being produced. Consequently, few tubers with poor viability were available to initiate production in the following year (J. Lennartson, U.S. Fish and Wildlife Service, Winona, Minnesota, personal communication). This hypothesis was based on a general model of macrophyte decline (Phillips et al. 1978).

More recent research has identified two other potential causal factors—low sediment nutrient concentrations and common carp (*Cyprinus carpio*). Low nutrient concentrations in the second drought year may have resulted from high plant uptake rates and low depositional rates during the first year (J. Barko, Waterways Experiment Station, Vicksburg, Mississippi, personal communication). This hypothesis conflicts with the traditional belief that sediment input into areas containing

submersed plants needs to be eliminated to provide as much light as possible. To the contrary, low levels of sediment input, with their associated nutrient load, may be necessary for continued plant survival from year to year.

Common carp are abundant in the UMR (Lubinski et al. 1986) and have the potential to affect macrophytes (Threinen and Helm 1959; Macrae 1979; Fletcher et al. 1985). Preliminary results from an ongoing experimental study in a backwater lake in Navigation Pool 8 indicate that high densities of carp can reduce densities of *Potamogeton crispus* and *Myriophyllum* spp.

Three important points about retrospective explanation of change on a large and complex ecosystem can be made using the above example. First, there is almost always a long list of factors that may have contributed to the change. In this case, the existence of many observers helped to limit the list of potential causal factors.

Second, spatial correlations alone may not help to make causal interpretations more conclusive. Spatial information indicated that the change in macrophyte production between 1988 and 1989 occurred in many UMR navigation pools in the Midwest. Therefore, no specific points of impact could be used to trace a causal factor. On one hand, one or more climate-related factors were implicated by the broad impact pattern. On the other hand, the change did not occur in Lake Pepin, a large floodplain lake in Navigation Pool 4 that acts as a sink for contaminants and other materials originating from the Minneapolis–St. Paul area. The available spatial data, therefore, did not help to narrow the list of potential causal factors.

Third, a retrospective explanation, even when presenting expert opinion as objectively as possible, will always include some level of speculation. A factor that may be limiting over a 2-year period may not be limiting for the next 10 years, a dynamic characteristic especially common to ecosystem components of floodplain rivers. Therefore, conventional wisdom and spatial or temporal correlations are often not sufficient to reliably limit a list of potential causal factors. Speculation can be reduced if a well-designed monitoring program is in place and the observations include controlling factors. But response thresholds (ecological criteria) must be known during interpretation to objectively eliminate factors from consideration. Such criteria are obtained almost exclusively from controlled experimental research.

The need to compare in situ measurements of controlling factors with applicable ecological criteria is typical of risk-analysis approaches to management (Cairns and Orvos 1990). The recognition of the need to make such comparisons has helped to establish productive research strategies within the LTRMP. A first step in the research strategy for aquatic macrophytes, for instance, was to construct a descriptive model of the factors that are perceived as influencing macrophytes on the UMR. The model assists in the identification of causal relationships (i.e., between light and growth of submergent macrophytes) that need to be quantified and ecological criteria that can be used for interpreting change.

The fact that much of our information about causal factors is limited and inconclusive has had an impact on the diversity of proposed habitat rehabilitation projects on the UMR. As noted earlier, most projects have attempted to address the common problem of sedimentation or its associated water quality and ecological impacts in areas that were created by impoundment (U.S. Army Corps of Engineers 1991b). Exceptions have included projects designed to increase surface areas of winter and summer refugia for backwater fish species, increase food production for migrating waterfowl, increase cover for ground-nesting waterfowl, and replace islands lost since impoundment to bank erosion.

In reality, justifications for many of the proposed habitat rehabilitation projects on the UMR have been based on relatively general theories about causal mechanisms and limiting factors. In the absence of conclusive information about what caused an unacceptable change, managers frequently have had to base their actions on a best guess. As described in the next section, anticipated benefits of some projects have not been realized, possibly due to site-specific exceptions to common perceptions about how the ecosystem of the UMR works.

Evaluation of Management Alternatives

Assuming the cause of a resource problem has been accurately explained, the action step requires knowledge of the most effective means of returning the ecosystem or its components to an acceptable level. This step requires the most funding and creativity on the part of the management agency.

More than any other information category, the evaluation of management alternatives is dependent on a variety of disciplines, including engineering, economics, and government operations, as well as ecology.

The spatial scale of a management alternative should match the scale of the problem. The most significant example on the UMR where alternatives currently do not address the appropriate spatial scale is the sediment loading problem. If a long-term ecological goal on the UMR is to maintain its current level of high quality backwater habitat, future management alternatives must include the opportunity to encourage the reduction of soil and bank erosion in the basin and stream network. Costs for such actions, however, will be enormous, as indicated in the Master Management Plan for the UMR (Upper Mississippi River Basin Commission 1982), which recommended that Congress authorize $91.2 million/year over a 10-year period to implement an accelerated program to reduce upland and tributary erosion. Watershed projects that include erosion reduction on a limited scale have been implemented (Hawkins and Stewart 1990). Some habitat rehabilitation projects, targeted at individual backwaters or impounded areas, have included small sediment control features for tributaries that empty directly into the project area (the legality of even these limited off-floodplain efforts was questioned early in the EMP). Sediment deposited in tributaries since the 1930's will probably take several decades to move through the system, so large-scale reductions in sediment loading must be considered a long-term solution, not a quick fix. Until the appropriate funds and mechanism for taking such action are found, it will remain a potential, instead of a real, alternative.

A management alternative that could be implemented at the navigation pool scale on the UMR is the modification of water regulation practices at dams to improve conditions for fish and wildlife (Lubinski et al. 1991). Two reports prepared by Corps Districts have described the physical, legal, and administrative constraints within which modifications to operational plans would have to be made (U.S. Army Corps of Engineers 1991a; Wilcox 1993).

Early ideas to use EMP funds for management alternatives other than habitat projects, such as restocking sturgeon and paddlefish populations, were rejected as being beyond program authorities. Land acquisition and the reclamation of agricultural land in the floodplain, which would be especially valuable in the open river below St. Louis, Missouri, was rejected for the same reason. In plans for future large river management programs, restrictions on the use of these or any other alternatives should be minimized if managers are to be fully capable of meeting ecosystem objectives.

Under the EMP, the predominant management alternatives that have been considered are habitat rehabilitation projects. Habitat projects include activities such as island construction, backwater dredging or the creation of potholes, construction of low levees and installation of water control structures, installation of culverts to restore water flow through backwaters, channel realignment with rock and fish-cover placements, and mast tree plantings (U.S. Army Corps of Engineers 1991b). It has often been difficult to define the effective zones within which these projects are expected to provide benefits. For evaluation purposes, benefits have typically been identified for a relatively limited area defined by the geomorphology of the area or the physical structures associated with the project.

Observations of two completed habitat projects indicate that success in meeting rehabilitation objectives will be variable. The Brown's Lake Project in Navigation Pool 13 seems to have been highly successful. Goals of the project were to increase depths and raise dissolved oxygen concentrations in a backwater that had filled with sediment in the 45 years following impoundment. The project included a deflection levee to prevent sediment-laden water from entering the area, a water control structure to divert oxygenated river water into the backwater, and hydraulically dredged channels to direct the flow of water through the area and return depths to postimpoundment levels. Post-project telemetry and water quality studies have demonstrated that opening the water control structure in winter raises dissolved oxygen concentrations past levels required to provide suitable habitat for largemouth bass (J. Pitlo, Iowa Department of Natural Resources, Bellevue, personal communication).

Conversely, the Weaver Bottoms Project (not funded under the EMP) in Navigation Pool 5 has not yet produced the ecological benefits anticipated. Goals of this project were to improve conditions for aquatic macrophytes, game fish, and puddle ducks by reducing the flow of water and sediment into the Weaver Bottoms area and by

creating two 6-ha islands to reduce resuspension of bottom sediments caused by wind action. Postproject monitoring has indicated that there has been little influence of the project on habitat quality for vegetation or wildlife. Reduced suspended solids input, water current velocities, and scouring did not result in lower turbidity levels or more aquatic vegetation. The lack of vegetation response may have been partly caused by limiting factors operating at greater spatial scales. A general vegetation decline in this reach was observed during the postproject period (see Causal Factors). Interpretations of why the project has not succeeded have included speculation that light may not have been the principal factor limiting aquatic plant growth (Davis and Nelson 1992). If so, this project serves as an example of what can happen when habitat rehabilitation efforts are based on incomplete information about causal factors. Our limited knowledge of causal mechanisms, especially how they might differ under special localized conditions, increases the probability of similar results as managers attempt other kinds of pioneering projects.

Unanticipated results of early rehabilitation actions on large rivers are inevitable. Such results need to be minimized, if for no other reason than they could be extremely costly. Under the EMP, about $161 million will be spent on habitat rehabilitation projects through 1997 (U.S. Army Corps of Engineers 1991b). Critical evaluation of the amount of information needed to go ahead with a proposed project will help to ensure success. The use of small-scale experimental projects to better predict ecological benefits may provide additional assurance. In addition, local project benefits need to be evaluated in the broader context of their value to the defined system.

Conclusion

The four information categories described above are not part of a formally recognized management process subscribed to by any single agency on the UMR. Rather, they are presented as elements of a conventional management process, parts of which have been implemented by different agencies during efforts to rehabilitate the river. Our intent has not been to describe how management is done on the UMR, but to describe how information can be used in the management process to achieve habitat rehabilitation.

Each category of information is vital to the management process. System status information (monitoring data), for instance, cannot replace system objectives or action levels. Nor can a manager depend completely on system status information, even if collected over many years, to explain why an ecosystem component changed or how to return the system to its previous level. Because these information categories play separate roles, a successful management program must include some effort to fill each category.

For most of the habitat rehabilitation projects on the UMR that have been completed or are in progress, it has been necessary for agencies to plan without having all of the necessary information. Debate about the eventual ecological value of many projects continues, often prompted by questions of whether the need for the project has been clearly justified, or whether perceived negative impacts to a component that was not considered in the project plan will override the benefits to the target component. Rehabilitation is costly, and obtaining the right kinds and quantities of information is critical to ensuring that expenditures will produce desired results. By understanding the roles of different pieces of information, we can more clearly differentiate information which is "nice to know" from information that is absolutely necessary to proceed with a project, thereby maximizing the chance for successful rehabilitation and maintenance of ecosystem objectives at the greatest possible scale.

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The Embarras River

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Abstract. The Embarras River originates on the south farms of the University of Illinois near Urbana, Illinois, flows about 310 km and drains an area of 6,250 km^2 in parts of 11 counties of east-central Illinois. Only one impoundment exists along its length. The watershed is 80–90% agricultural; corn and soybeans are predominant. About 10% is forested and about 5% is urban. Considerable drainage of wetlands and dredging have occurred. Eighteen municipal wastewater treatment plants discharge their treated effluents in tributaries (14) or in the mainstem (4) of the system. Other intermittent dischargers also affect the system. Present water quality problems, based on water quality indices (WQI), are minimal to minor and are caused primarily by total suspended solids and total phosphorus. Macroinvertebrate studies (MBI values) also indicate good to very good water quality. Of 39 species of freshwater mussels reported, nine have been proposed for the state endangered species list; one of these is also proposed for the federal list. Index of Biotic Integrity (IBI) values in one study ranged from 28 to 50. The middle section of the river has been characterized by some biologists as one of the outstanding streams of Illinois. Three endangered fishes (eastern sand darter, harlequin darter, and bigeye chub) have been reported from the mainstem. The bigeye shiner, a threatened species, also has been reported. The major warmwater fishes present are cyprinids (28), percids (15), catostomids (14), centrarchids (12), and ictalurids (9). At least 101 species have been reported since 1899, and at least 89 species inhabit the system at present. Commercial fishing has been almost nonexistent since 1950. Sport fishing occurs along most of the river. The major problems needing attention are silt load from agricultural fields, oil field wastes, and the need for wastewater treatment plant improvements. Erosion control is the primary need.

The Embarras River is a relatively small (seventh-order) stream compared with many others covered in this symposium. Its somewhat unusual name, at least according to local legend, stems from an occasion when a French army officer was supposedly captured while bathing nude in the river. He was quoted as saying it was an embarrassment (Embarras). The name stuck, apparently.

The river has been fairly well studied over a period of many years. While few of these studies have involved extensive details of all aspects of the river, there are enough details to give a reasonable picture of the river.

This paper synthesizes the available information about the river and includes observations and data that I have accumulated over a period of about 43 years. The initial portion covers basin description, including location, physiography, geology, land use, climate, and hydrology. Physical and chemical changes in the river basin follow. These include channelization, draining of wetlands, damming, water quality (including chemical spills and nutrient levels), and quantitative data relative to levels of some of the important elements and compounds measured. Macroinvertebrates (including freshwater mussels) are discussed, followed by a description of the fishes reported as present in the river during a period of over 90 years. The future of the river is the final topic addressed.

Basin Description

Location

The Embarras River, a tributary of the Wabash River, has its headwaters in Champaign County, Illinois, and meanders southward through rich farmland on Wisconsin glacial till until it cuts through the Shelbyville Moraine near Charleston in Coles County. (Fig. 1) For several miles downstream from Charleston the river has deposited large quantities of glacial gravel from the thick morainal deposits (Page and Smith 1971). Near Newton in Jasper County, it veers toward the southeast and flows over a bed of predominantly sand and Illinoian clays. The river empties into the Wabash River near Billett in Lawrence County. It drains about 6,250 km^2 in its 310-km course through eastern Illinois (Healy 1979). Portions of 11 counties are drained by the river. The North Fork of the Embarras River, which is 75.5 km long and drains 803 km^2, is the only major tributary and joins the Embarras southeast of Saint Marie in Jasper County. Numerous other tributaries having total lengths and drainage areas considerably less than that of the North Fork are located throughout the basin. The largest cities are Charleston (19,400), Lawrenceville (5,650), and Mattoon (19,800). Lake Charleston, a 145.7-ha lake, is the only impoundment.

Physiography

The topography of the Embarras River basin is the result of recent modification of glacial activity during the Wisconsinan and Illinoisan periods (Ettinger 1989). The northern part of the basin, above the Cumberland–Coles county line, is within the Bloomington Ridged Plain and is described by Wangsness (1983) as depositional plains of low relief underlain by thick till and slightly modified by postglacial stream erosion. The plains are nearly flat to gently rolling and are crossed by several low and poorly developed end moraines. The flatness of the plains is broken by low eskers, esker troughs, and meltwater drainways that trend southeast.

The central portion of the basin is within the Springfield Plain and extends from near the Cumberland–Coles county line on the north to the Richland–Jasper county line (Wangsness 1983). This area was not subjected to the more recent Wisconsinan glacial activity but was glaciated in the Illinoisan period. It is underlain by lacustrine, outwash, and alluvial sediments and till and is characterized by extensively aggraded valleys. The lowlands are broad plains with low rolling hills. The northern end of the plain has less relief than the southern end.

Downstream from the Richland–Jasper county line, the basin is within the Mt. Vernon Hill Country, which has gently rolling topographic features that are controlled chiefly by the underlying bedrock. The uplands are well dissected, and the lowlands are broad and have low-gradient alluvial river plains (Wangsness 1983).

Elevation in the Embarras River basin ranges from 218 m mean sea level (msl) at its source near Urbana to 123 m msl at its confluence with the Wabash River, a fall of 95 m. Total river length is 310.4 km, so the average slope is 0.32 m/km. Average headwater slopes of the mainstem are relatively steep, about 0.88 m/km, while the middle reaches average 0.32 m/km. The outlet reach between the Wabash River and the U.S. Geological Survey stream gage at Ste. Marie averages only 0.29 m/km (Guillou 1976).

Geology

The uppermost bedrock in the Embarras River basin is primarily Pennsylvanian, with a small area of Mississippian and Devonian bedrock in western Douglas and southwestern Champaign counties (Wangsness 1983). The bedrock is covered by glacial deposits from the Kansan, Illinoisan, and Wisconsinan glaciers. No surface deposits of the Kansan drift are known, while Illinoisan deposits cover the lower half of the Embarras basin. Thickness in the area covered by only the Illinoisan deposits ranges from about 15 to 61 m. Loess associated with the Illinoisan glaciation is thin because of interglacial weathering. Wisconsinan drift covers the upper half of the basin, and its thickness ranges from 50 to 400. Wisconsinan loess covers most of the Embarras basin, and a depth of 1.2 m is common, although depths as great as 2.4 m can be found in areas adjacent to the Wabash River (Wangsness 1983).

Herrin Coal (No. 6) and Springfield Coal (No. 5) underlie most of the Embarras River basin, although only Crawford and Douglas counties have had active coal mines. The Crawford County mines have not been in operation for more than 10 years, and the Douglas County mines (Zeigler Coal Company) have recently closed for economic reasons. As of 1984, Zeigler had mined 34.6 million metric tons of coal from its two mines near Murdock, Illinois (Neely and Heister 1987).

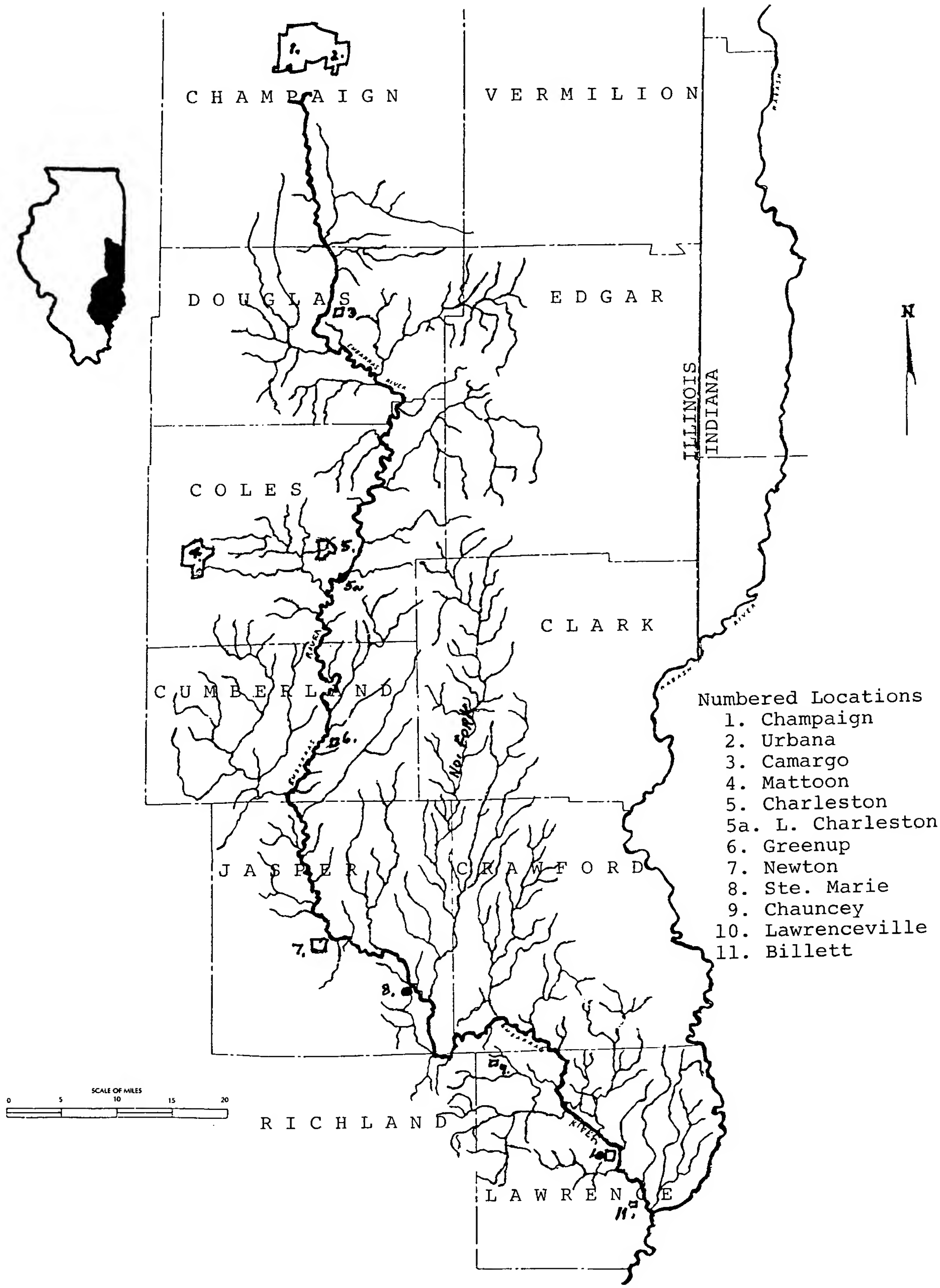

Fig. 1. Location of the Embarras River system in Illinois. The 11 counties drained by the system are indicated.

Crude oil has been produced in Lawrence and Jasper counties since 1908. With secondary recovery methods, this production has continued to the present, enabling Lawrence County to produce 10% of Illinois' total crude oil in 1984. With the exception of Champaign County, all of the counties in the Embarras basin have produced over 1 million barrels since 1908. Because of this large production, two oil refineries at Lawrenceville and Robinson serve the area (Morris 1961; Neely and Heister 1987).

In the pre-Wisconsinan Drift area the characteristic soils are silt and clay loams with dense clayey subsoils. These soils are strongly acidic, developed from loess material deposited on heavily weathered Illinoisan Drift. Drainage is a serious problem on the more level land, where claypan subsoils hinder the subsurface movement of water. On the sloping land, this same lack of internal drainage requires that erosion control measures be made an integral part of any farming operation.

Land Use

The Embarras River watershed is primarily agricultural; 80–90% of the area of each county is in farms. The counties with the largest percentages of nearly level land have more than 90% of the total county area in farms, while Crawford and Lawrence counties, with a higher percentage of hilly land, have somewhat less than 80% of the area in farms. In 1986, the Illinois crop reporting district that encompasses the Embarras basin ranked fourth out of nine districts for corn yield and fifth out of nine for soybean yield (Barrett 1987). About 10% of the land is forested, and 5% is urban.

Climate

The climate of Illinois has been classified as humid-continental, with the weather principally influenced by masses of cold polar air moving to the east across the basin and by warm moist Gulf of Mexico air masses crossing the basin from the south toward the east. Prevailing winds, in order of importance, are from the southwest, west, and northwest.

The average annual precipitation is about 990 mm (Table 1), and average annual snowfall is 406–432 mm, but the snow does not usually remain on the ground for long periods. Precipitation is usually well distributed throughout the year. The driest months are normally January and February, and the wettest are May, June, and July. (Guillou 1976)

During summer, when gulf air masses control the precipitation pattern, there is wide variation in rainfall over the basin. Heavy thunderstorm rainfall may occur over a principal tributary, causing mainstem flooding in an area that may have experienced no rainfall. The combination of highly variable summer precipitation and poor moisture retention characteristics of the soil often produces very droughty areas, when the actual rainfall is near the average value.

Hydrology

The average stream flow for the Embarras River at the U.S. Geological Survey stream gaging station at Ste. Marie, Illinois, for the last 75 years has been 1,237 cubic feet per second (cfs). The maximum discharge during this same period was 44,800 cfs on 4 January 1950, and the minimum flow was 1 cfs on 5–9 October 1914 (Stahl et al. 1987). Average stream discharge for the April through October 1987 sampling period was about 432 cfs. The daily maximum discharge during this period was 4,400 cfs on 2 July 1987, and the daily low was 30 cfs on 27–28 September and 22–23 October 1987 (U.S. Geological Survey provisional data). The stream gage at Ste. Marie measures about 62% of the Embarras River basin.

Mean stream width for the Embarras during the 1987 study (Ettinger 1989) was 20.4 m, although it varied from 37.4 m (at Newton) to 5.8 m (at Philo). Mean stream depth was 0.26 m. Sand was the predominant substrate (41%), followed by gravel (21%) and silt/mud (10%).

Table 1. 1987 monthly and long-term (1951–80) precipitation averages (mm) for the Embarras River basin (Illinois State Water Survey 1988)

Month	1951–80	1987
January	55	56
February	56	20
March	92	37
April	98	69
May	101	45
June	107	94
July	107	86
August	81	47
September	76	56
October	63	39
November	76	107
December	75	146
Annual	987 (mean)	902

All of the tributaries to the Embarras River have a 7-day, 10-year low flow of zero with the exception of the North Fork of the Embarras River and Kickapoo Creek. In addition, the mainstem above the Champaign–Douglas county line also has a zero low flow (Singh et al. 1988). During the 1987 survey by Ettinger (1989) 37 sites on 34 different streams were found to be either dry or pooled. These streams were at least third-order, as determined by Strahler (1957). Several of the stations sampled in April or May were probably dry by the end of the study in October.

Physical and Chemical Changes of the Embarras Basin

The drainage area in the northern limits of the Embarras watershed is nearly level prairie land drained by numerous artificial waterways consisting of open levee ditches, channelized streams, and numerous tile lines draining productive farmland into the slow-flowing main waterway (Lopinot 1962).

No portion of the basin is without problems of water control. These range from poor to improper drainage in the upper reaches to improper drainage and subsequent erosion as the water flows from the rolling uplands and enters the main waterway or tributaries feeding the main waterway of the lower reaches of the basin. Within these lower reaches the periodic flooding of the flat valley containing the main waterway and subsequent erosion presents a yearly threat to agriculture (Lopinot 1962).

The water table has been lowered with accelerated drainage. The stream has become wider, shallower, and much more variable in size and amount of flow than it was before the establishment of drainage districts and canals (Larimore and Smith 1963). During periods of drought the river becomes very low, and many of the once permanent tributaries dry up (Smith 1968).

Many of the wetland areas of the lower portion of the river basin have been drained over the years for agricultural purposes, highway construction, and other developments. Canalization has been most intensive in the lower course of the Embarras River. In fact, more than 16 km of the lower river occupies a manmade channel (Smith 1968). Forbes and Richardson (1908) referred to a swamp area in Lawrence County known at the time as Purgatory Swamp; it was 16 km long and 6.4 km wide. I was unable to find anyone who knew of this area at the present time. Possibly the 62-ha Chauncey Marsh Nature Preserve and surrounding 372-ha natural area are remnants of Purgatory Swamp because they represent the best remaining examples of that type of habitat in the area.

The impoundment on the Embarras below Charleston, Illinois, has changed much in the past 10 years. Originally constructed in 1947, the dam replaced a low-level dam that served to hold back a pool large enough to serve as the water supply for Charleston. The new dam was built directly across the river, creating a 162-ha lake. By the 1970's, the lake had a serious siltation problem. After a proposed U.S. Army Corps of Engineers dam project was defeated, the city of Charleston built a side-channel reservoir (146 ha), which incorporated most of the old lake, and dug a new channel for the river, which then by-passed the reservoir. The old dam was retained to have a pool from which to pump to supply the side-channel reservoir as needed. This project was completed by 1982. Several years later, the old dam gave way and was later replaced. The dam serves as an effective barrier to upstream movement of fishes, except during very high water levels.

In the 1970's, when the price of soy beans increased dramatically, bulldozing of trees along the Embarras to increase available acreage was a fairly common occurrence. In many instances, these trees were simply pushed over the bank into the stream, which occasionally caused the stream to erode a new channel around the debris (personal observations).

Water Quality

Water quality in many of the tributaries has improved considerably since the 1960's, primarily through improved sewage treatment. The two largest cities in the Embarras drainage system, Charleston and Mattoon, have either built new sewage treatment plants or entirely renovated their old plants. The plants discharge their effluents into Cassell Creek (Charleston) and Kickapoo Creek (Mattoon) in Coles County. Cassell Creek then empties into Kickapoo Creek. As described in Durham and Whitley (1971), a septic zone stretched for 6.4 km eastward along Kickapoo Creek as a result of the Mattoon plant discharge. Just as it was about to clear up somewhat, the Charleston plant effluent joined it, and another septic zone of about 1.6 km resulted. These septic areas have been eliminated since the mid-1970's.

There are numerous discharges within the Embarras River basin, including municipal wastewater treatment plants (Table 2) and industries such as Anamet, Inc., General Electric Co., Cabot Corporation, and Texaco Refining and Marketing, Inc. In addition, there are also intermittent discharges from schools, mobile home parks, motels, feedlots, public water supplies and other small business operations. All of the treatment plants have been either built or upgraded since the 1970's.

Several serious chemical spills have affected the Embarras. In 1963, a metal-plating plant dumped 9,460 L of sodium cyanide into a drainage ditch that by-passed the Mattoon, Illinois, wastewater treatment plant. The material entered Kickapoo Creek, killing everything in the 16-km tributary, and then entered the Embarras and eliminated animal populations for a distance of 19 km. This occurred during a relatively low water period; movement downstream was relatively slow and was monitored for several weeks. After that time, a heavy rain flushed and diluted the material to a point where it was no longer toxic. Thousands of fish and other aquatic organisms, four cattle, and some dogs were killed as a result of this dumping. Court cases were delayed several years before any blame was determined.

In 1969, a train wreck on the east edge of Charleston resulted in another cyanide spill that potentially could have entered a small creek (Town Branch) and eventually entered the Embarras. The cyanide was contained with a series of berms and eventually treated using a reverse septic system. The treatment at the spill cite continued into 1974 (over 3.5 years).

Oil production, while seemingly not confined to any one land surface characteristic, is often found near the immediate drainage channels of the small tributaries in the lower portion of the basin. The practice of purposeful and periodic flushing of oil field wastes, in combination with the unintentional discharge of oil field wastes into the drainage, decimates fish populations and animals in the drainage. This condition has existed since the discovery of oil in the basin in the early 1900's. New oil recovery methods have not reduced the problem but have led to an increase in discharges or at least the threat of the release of large volumes of discharge (Lopinot 1962).

Studies of water quality in the Embarras basin have been carried on for a number of years. Har-

Table 2. Municipal wastewater treatment plant dischargers in the Embarras River basin (from Ettinger 1989).

City	1986 population	Receiving stream	County	Treatment process	Design ave. flow (mgd)[a]	1987 ave. flow (mgd)
Arcola	2,714	Spoil Bank Trib.	Douglas	Lagoon, sand filter	0.50	0.52
Bridgeport	2,281	Indian Creek	Lawrence	Lagoon, sand filter	0.25	0.19
Casey	3,026	Quarry Branch	Clark	Activated sludge, RBC's, and sand filter	0.40	0.31
Charleston	19,355	Cassell Creek	Coles	Activated sludge	4.00	2.67
Flat Rock	493	Brushy Creek	Crawford	Lagoon, sand filter	0.07	0.05
Greenup	1,655	Embarras River	Cumberland	Lagoon, sand filter	0.19	0.10
Lawrenceville	5,652	Embarras River	Lawrence	Activated sludge	1.00	0.51
Martinsville	1,298	North Fork Embarras River	Clark	Lagoon, sand filter	0.15	0.25
Mattoon	19,787	Kickapoo Creek	Coles	Activated sludge and sand filter	4.50	3.63
Newton	3,186	Embarras River	Jasper	Activated sludge	0.50	0.27
Oakland	1,035	Hog Branch	Coles	Lagoon, sand filter	0.17	0.13
Oblong	1,840	Dogwood Creek	Crawford	Lagoon	0.23	0.21
Summer	1,238	Crabapple Creek	Lawrence	Lagoon, sand filter	0.20	0.10
Toledo	1,284	Cottonwood Creek	Cumberland	Lagoon, sand filter	0.18	0.21
Tolono	2,434	Hackett Branch	Champaign	Activated sludge and polishing pond	0.30	0.15
Tuscola N.	3,839	Hayes Branch	Douglas	Trickling filter	0.28	0.21
Tuscola S.		Scattering Fork	Douglas	Activated sludge	0.61	0.31
Villa Grove	2,707	Embarras River	Douglas	Activated sludge and sand filter	0.60	0.56

[a] mgd = million gallons per day.

Table 3. Chemical analyses of Embarrass River water taken at the Camargo Gaging Station reported by Harmeson et al.(1973). Ranges are indicated for the year. Mineral constituents are in milligrams per liter and turbidity in Jackson Turbidity Units.

Year	Fe	Mn	Ca	Mg	Sn	Na	K	NH_4
1967	0.1–7.6	0.00–0.42	54.2–81.4	26.4–31.5	0.11–0.19	6–66	0.6–4.9	0.0–0.8
1968	0.3–5.4	0.00–0.19	42.4–75.2	25.2–33.6	0.08–0.16	6–36	0.8–6.1	0.1–0.3
1969	0.1–2.1	0.00–0.28	37.2–80.0	16.8–32.8	0.07–0.21	5–16	0.8–6.0	T–0.7
1970	0.1–3.5	0.00–0.40	56.0–84.0	24.4–37.1	0.09–0.17	7–21	0.7–2.9	T–0.1
1971 (thru Sept)	0.7–10.0	0.00–0.18	27.2–82.4	7.8–33.7	0.08–0.16	5–23	0.9–4.6	0.1–0.6

Year	PO_4	NO_3	Ca	SO_4	Alk.	T.H.[a]	Cu	Zn	Turb.
1967	0.10–4.10	0.3–47.8	14–63	61–88	176–256	244–332	0.01–0.02	0.00–0.04	2–138
1968	0–4.60	0.2–68.7	9–43	34–99	126–240	173–316	0.01–0.03	0.01–0.06	3–97
1969	0–1.00	2.9–46.3	14–20	39–80	126–242	162–330	0.01–0.07	0.01–0.08	2–47
1970	0.10–0.90	1.1–44.3	18–27	47–89	168–244	240–362	0.00–0.62	0.01–0.08	3–69
1971 (thru Sept)	0.10–1.30	2.4–44.8	9–22	33–77	64–240	100–340	0.01–0.04	0.01–0.10	16–296

[a]Total hardness.

meson et al. (1973) showed data covering analyses of samples from the Embarras at Camargo, Illinois, from 1966 to 1971. Neinkerk and Flemal (1976) showed analyses of dissolved solids from the Camargo station for 1961–71, and the Ste. Marie station for 1959–61. Durham and Whitley (1971) included analyses for 1967–70 in their study. Ettinger (1989) gave the most recent available data. A very recent report (Illinois State Water Survey 1992) with no data indicated the upper Embarras River water quality was acceptable according to the state's general-use standards.

There seems to be no real change over the years in the levels of those variables measured, in that data from each study fit within the ranges given by Harmeson et al. (1973), which were on a monthly basis. The variables measured included iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), tin (Sn), sodium (Na), potassium (K), NH_4, PO_4, NO_3, chlorine (Cl), SO_4, copper (Cu), zinc (Zn), alkalinity, total hardness, and turbidity. Table 3 shows the results of Harmeson et al. (1973) as representing the conditions of the river for these variables. Table 4 shows the median and high values of some of the same variables for the 10-year period 1961–71.

Ettinger (1989) reported on water quality in the river basin in the form of a Water Quality Index (WQI). This index compares physical and chemical water quality data with established criteria and reports the result as a single value (Illinois Environmental Protection Agency 1986). The index characterizes water quality (on a scale of 0–100) in comparison with water quality standards and aquatic life requirements. The various ranges of WQI values indicate the degree of impact (Illinois Environmental Protection Agency 1988): 0.0–30.0, minimum water quality prob-

Table 4. Median and high values of stream characteristics of the Embarras River near Camargo. Mineral constituents in milligrams per liter and turbidity in Jackson Turbidity Units.

Years	Total dissolved minerals		Total hardness		Chloride		Sulfate	
	Median	High	Median	High	Median	High	Median	High
1966–1971	373	481	291	362	19	220	30.9	68.7
1961–1966	340	629	275	394	14	78	17.6	15.0
	Nitrate		Iron		Soluble phosphorus		Turbidity	
1966–1971	30.9	68.7	13	10.0	0.45	1.52	34	296
1961–1966	17.6	45.0	14	6.3	0.4	1.96	28	126

lems; 30.1–50.0, minor water quality problems; 50.1–70.0, moderate water quality problems; and 70.1–100, severe water quality problems.

Ettinger computed WQI values for five Ambient Water Quality Monitoring Network (AWQMN) stations in the Embarras River for the years 1984–88. These values ranged from 18.9 to 40.1, indicating only minor problems, which were mainly because of total suspended solids and total phosphorus, and total dissolved solids to a lesser extent.

Ettinger also indicated the violations or potential violations of state water quality standards found in sampling 56 stations. A single grab sample was taken at each station. The numbers of violations of standards (in parentheses) were as follows: dissolved oxygen (5 mg/L), 8; pH (6.5–9.0), 1; total dissolved solids (1,000 mg/L), 3; unionized ammonia (0.04 mg/L), 1; total phosphorus (0.05 mg/L), 14; total iron (1 mg/L), 25; and total manganese (1 mg/L), 10.

The high levels of manganese and iron occur naturally and are not the result of discharges into the stream system (all Illinois streams are rich in iron, Harmeson 1973). The low dissolved oxygen levels were because of low flow conditions and the presence of naturally occurring organic material. The three high TDS levels and one pH level were associated with oilwell brine. A waste-water treatment plant at one site also may have contributed to the high TDS level. The one unionized ammonia violation also was attributed to the same treatment plant. High total phosphorus levels were associated in several areas with wastewater treatment plants. However, at most stations the phosphorus concentration probably was from nonpoint agricultural runoff.

Nutrient Levels

Amounts of nutrient nitrogen and phosphorus in the Embarras at the Camargo station were measured by Harmeson et al. (1973; Table 5). These figures are somewhat in the high range compared with other streams measured in the same years. A major concern of high nutrient levels is the stimulation of algal growth, which has not been a problem on the Embarras River (personal observations).

High phosphorus levels are often associated with high turbidity. Since phosphorus applied to land is generally thought to be rather tightly bound to the soil particles, sediment washed into the stream can carry significant amounts of phosphorus with it.

Biology of the River

Macroinvertebrates

Macroinvertebrates can be used to evaluate water quality (Ettinger 1988; Cummings et al. 1989). Each species is dependent on specific ranges of environmental conditions (i.e., water quality, habitat, flow) throughout its lifespan. The resulting community indicates conditions during weeks and months before collection. The macroinvertebrate community is especially useful under conditions of intermittent or mild organic enrichment, when altered water quality is not readily detectable by conventional chemical surveys (Chutter 1972). The underlying rationale is that good water quality supports a diverse community containing pollution-intolerant forms and that organic enrichment tends to restrict the number of species and to increase the density of pollution-tolerant species (Keup et al. 1967).

In the 1987 study (Ettinger 1989), qualitative macroinvertebrate samples were collected according to Illinois Environmental Protection Agency guidelines (IEPA 1988). Macroinvertebrates were identified to the species level when possible, and a Macroinvertebrate Biotic Index (MBI) was calculated for each site.

The MBI, as used by Illinois Environmental Protection Agency, is a modification of one developed by Hilsenhoff (1982). Each taxon has been assigned a pollution tolerance value from 0 to 11 based on available literature and previous field experience. A value of zero is assigned to taxa known to occur

Table 5. Levels of nitrogen and phosphorus in milligrams per liter and the yield of each in kilograms per hectare in the Embarras River at the Camargo station for the years 1961–66 and 1966–71 (Harmeson et al. 1973)

Years	Nitrogen		Phosphorus	
	mg/L	kg/ha	mg/L	kg/ha
1967–66	19.1	16.2	0.71	0.21
1966–71	27.4	16.8	0.67	0.27

Table 6. Summary of macroinvertebrates collected from the Embarras River and its tributaries (Ettinger 1989).

Location	Total no. of taxa	No. of stations	No. of unique taxa	Range in no. of taxa per station	Mean no. of taxa per station
Mainstem	79	15	12	18–35	28
Tributaries	102	41	35	8–36	22

in unaltered streams of high water quality. A value of 11 is assigned to taxa known to occur in severely polluted or disturbed streams. Intermediate values are assigned based on an organism's relative degree of tolerance or intolerance to pollution. The MBI_i for each taxon is calculated from the formula:

$$MBI_i = (n_i t_i)/N,$$

where n_i = the number of individuals in each taxon, t_i = the tolerance value assigned to that taxon, and N is the total number of individuals in the sample. The MBI is an average of tolerance values of all taxa at a station, weighted by abundance, and is used as a measure of stream condition (Ettinger 1989). Based on present assessment methods, MBI values reflect water quality as follows (Illinois Environmental Protection Agency 1988):

5.0 Excellent
5.0–6.0 Very good
6.1–7.5 Good/fair
7.6–10.0 Poor
>10.0 Very poor

Table 6 summarizes macroinvertebrate collections made in 1987 (Ettinger 1989). Only five tributary sites exhibited 10 or fewer macroinvertebrate taxa per station. Of these five sites, Dogwood Creek, near Oblong, was downstream from the Oblong municipal wastewater treatment plant, and the other four were all associated with oil fields. Ephemeroptera (mayflies) comprised the most abundant assemblage in the macroinvertebrate community (26 taxa), followed by Odonata (dragonflies and damselflies, 23 taxa) and Trichoptera (caddisflies, 15 taxa). The mayfly *Stenacron interpunctatum* was the most common organism, appearing in 45 of 56 samples.

Macroinvertebrate biotic index values for the mainstem ranged from a high of 6.4 at Lawrenceville to a low of 4.3 at two sites below the Lake Charleston dam and near Ashmore. Six stations had MBI's below 5.0, indicating excellent water quality. The mean value for the mainstem was 5.0, reflecting very good water quality overall.

Variations in MBI values for the Embarras River were probably due to subtle differences in microhabitat rather than water quality. Note the cyclic variation of MBI values indicated in Fig. 2. This periodicity coincides with changes in basin physiography. The headwaters of the Embarras are located on the Bloomington Ridged Plain. Near the Douglas–Coles county line the river enters the Springfield Plain, and finally, near the Jasper–Richland county line it flows through the Mt. Vernon Hill Country. The MBI values seem to rise as the river flows through the middle of a physiographic region and then fall quickly at the junction of two different regions.

The MBI values for the tributaries of the Embarras River ranged from a high of 8.2 on Indian Creek near Lawrenceville to a low of 4.4 at three sites, including North Fork Embarras River near Ste. Marie, Allison Ditch near Billett, and Willow Creek near Oblong. Ten tributaries had an MBI less than 5.0, reflecting excellent water quality. The average value was 5.6 for all tributaries. The study of Durham and Whitley (1971) was not as extensive as the above but showed similar levels of macroinvertebrate quality and quantity.

Freshwater Mussels

The distribution and status of freshwater mussels in the Embarras River were studied during 1986–87 by the Illinois Natural History Survey (Cummings et al. 1988). This study incorporated 25 stations on the Embarras River, including 14 colocated with Illinois Environmental Protection Agency sites, and compared current mussel populations with data collected during a similar study in 1956. Thirty-two species of mussels have been documented as living in the Embarras River, and an additional seven species have been collected as dead shells only. During 1956, 29 species were reported as extant, but in 1986–87 this number dropped to 27 (Cummings et al. 1988). This total included 24 extant taxa that were common to both studies. The Cummings study showed an 86%

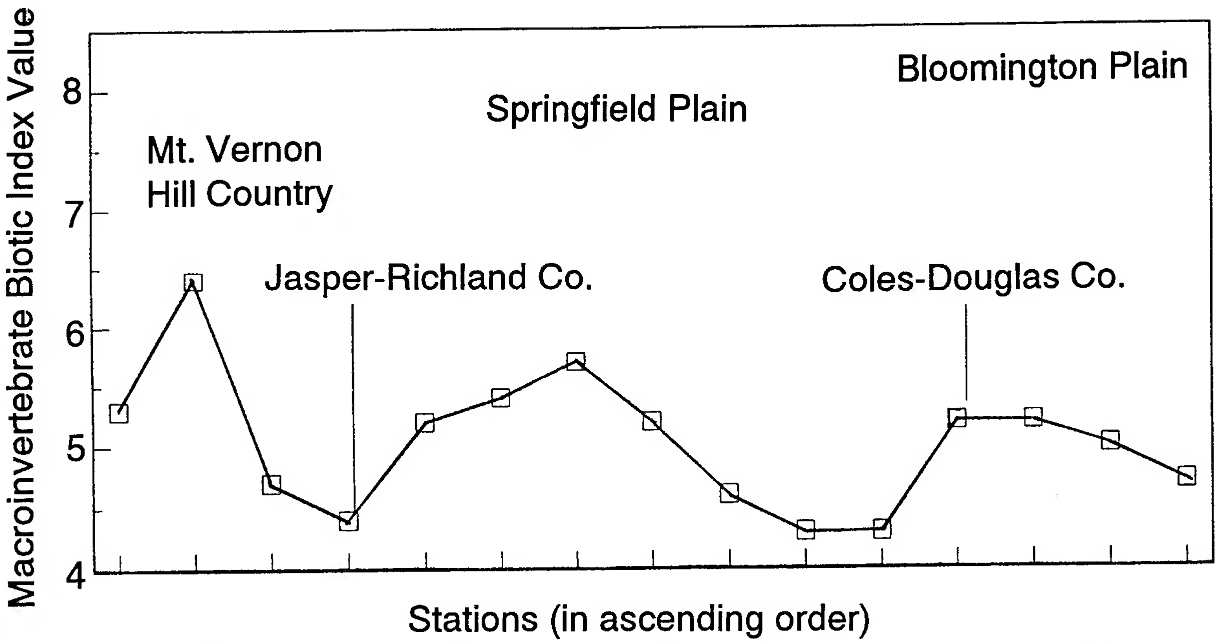

Fig. 2. Biotic index values of invertebrates collected from 15 stations on the mainstem of the Embarras River in 1987 (from Ettinger 1989).

Table 7. Number of fish species collected from the Embarras River system, collecting methods used, and number of stations or collections sampled.

Survey dates	Method	Number of stations or collections	Number of species	References
		Entire river		
1899–1901	Mesh seines	25	44	Forbes and Richardson (1908)
1962	Mesh seines and rotenone	20	51	Lopinot (1962)
1967	Mesh seines and rotenone	35	59	Lopinot (1962)
1974	Mesh seines and boat shockers	35	70	Price (1974)
1978	Literature, mesh and electric seines	83		Smith (1978)
1987	Electric seines	25	62	Ettinger (1989)
		Coles County		
1900–10	Mesh seines	10-year period	72	Hankinson (1913)
1967–70	Mesh and electric seines, boat shocker, creel	234 collections, 55 stations	83[a]	Durham and Whitley (1971)
		Champaign County		
1930	Mesh seines	19	25	Thompson and Hunt (1930)
1959	Mesh and electric seines	32	28	Larimore and Smith (1959)
1971–73	Mesh seines	9	28	Buth (1974)
1991	Mesh and electric seines	19	37	Osborne et al. (1991)

[a] Includes species taken through 1986.

reduction in the total number of all mussels had occurred between 1956 and 1986–87. Unfortunately, no cause for this decrease was given. However, several stations in the middle section of the river between Oakland and Greenup still supported a relatively diverse fauna. No commercial mussel fishing is permitted in the Embarras River.

Of the 39 species of mussels reported for the Embarras River, 9 have been proposed for the state endangered species list, and one (*Cyprogenia stegaria*) is also a candidate for federal endangered status. The nine species are *Cyprogenia stegaria, Epioblasma triquetra, Ptychobranchus fasciolaris, Obovaria subrotunda, Villosa iris, Villosa lienosa, Quadrula cylindrica, Plethobasus cyphyus,* and *Toxolasma lividus* (Cummings et al. 1988).

Fishes

The first extensive collections of fishes from the Embarras River basin were made by personnel from the Illinois State Laboratory of Natural History under the direction of S. A. Forbes (1908). Most of these collections were made in the 3-year period 1899–1901 (Smith 1968) and published in 1908 by Forbes and Richardson.

Three Illinois Department of Conservation studies (Lopinot 1962, 1967; Price 1975), the book titled *Fishes of Illinois* by Smith (1978), and the study by Ettinger (1989) covered most of the length of the river and its tributaries. Many of the river studies have been done on an individual county basis. Thompson and Hunt (1930), Menzel (1952), Larimore and Smith (1963), Buth (1974), and Osborne et al. (1991) covered Champaign County only. Hankinson (1913) and Durham and Whitley (1971) covered Coles County only. Methods of collecting must be considered when one compares studies. Each method has its own bias. Table 7 indicates the method or methods used in each study. Water levels, time of year, length of time spent collecting, number of stations, and other factors also influence which species are caught.

Data covering a period of over 90 years (1899–1991) were reviewed. The following discussion attempts to determine a valid list of extant species and a time sequence of appearance or disappearance of a species from the 11 studies listed.

One hundred one species of fish from 19 families have been reported from the Embarras and its tributaries (Tables 8 and 9). Several of these are more recent, imported fishes that have been moved around the state for various reasons. Two of these, not previously reported but collected by me or my students, are the grass carp and silver carp, collected in 1978 and 1986, respectively. The skipjack herring, mosquitofish, redear sunfish, white bass, and yellow bass are also imported species. The northern pike in Coles County was probably brought in from Wisconsin by a minnow dealer whose business was near where the 2.3-kg specimen was taken.

Twenty species were reported in all 11 studies reviewed:

Grass pickerel	Silverjaw minnow
Yellow bullhead	Creek chub
Bluntnose minnow	Blackstripe topminnow
Golden shiner	Stoneroller
Striped shiner	Spotted sucker
Bluegill	Sand shiner
White sucker	Green sunfish
Redfin shiner	Creek chubsucker
Longear sunfish	Spotfin shiner
Black bullhead	Johnny darter

The only study not including the spotfin shiner since it was separated from the steelcolor shiner complex was that of Ettinger (1989). It was undoubtedly included in his steelcolor shiner totals, based on the high percentage (35%). Durham and Whitley (1971) reported 21% spotfin shiner and 13% steelcolor shiner in their totals.

Considering only the studies covering the entire Embarras basin, there were 16 additional species in each of the six studies:

Brindled madtom	Channel catfish
Rainbow darter	Suckermouth minnow
Spotted bass	Logperch
Steelcolor shiner	Largemouth bass
Silvery minnow	Bullhead minnow
Blackside darter	Orangespotted
Golden redhorse	Slenderhead darter
Sunfish	Hogsucker
Greenside darter	

Another 10 species, although not recorded in all of the entire basin studies, were taken in the earliest (1899–1901) and latest (1987) collections, indicating continuous presence:

Emerald shiner	White crappie
Highfin carpsucker	Fathead minnow
Fantail darter	Shorthead redhorse
Brook silverside	Pirate perch
Eastern sand darter	Black crappie
River shiner	

Seven species first reported by Hankinson (1913) and collected over a 10-year period from the Embarras system in Coles County have shown continuous presence since then; these were missed by Forbes and Richardson (1908):

Carp	Freckled madtom
Gizzard shad	Dusky darter
Bigmouth buffalo	Slough darter
Flathead catfish	

Using Hankinson's (1913) hypothetical list of species that he expected to be in the county but did not collect, the silver redhorse and warmouth would fit the above category of continuous existence in the river system.

Four other species on Hankinson's hypothetical list and two others that he actually collected were also caught in later studies up through 1974. Of these, the American eel and bowfin are occasionally reported at the Lake Charleston dam. The black buffalo, smallmouth buffalo, and goldeye are most easily taken by boat shocker and may have been missed in the later studies using small-mesh and electric seines. The rock bass occurs very sporadically but is believed to still be present in the river.

The smallmouth bass and sauger, reported in the earliest studies, have not been reported since the 1970's. However, they are caught occasionally by local fishers in Coles County, most recently in 1991. Not numerous, they seemingly are not readily collected by small-mesh seines in the river.

Eight species not previously mentioned above were caught in the latest studies (1987, 1988):

Orangethroat darter	American brook lamprey
River carpsucker	Quillback
Ribbon shiner	Black redhorse
Mountain madtom	
Silver lamprey	

The American brook lamprey often seems to be scarce because of the difficulty of catching it out of the substrate into which it is usually burrowed. However, on the occasion of the cyanide kill in 1963, literally hundreds of this species were collected in a relatively short stretch of the river.

Freshwater drum, longnose gar, shortnose gar, paddlefish, and chestnut lamprey are encountered only occasionally in the Embarras. They were first reported in 1967–70 (Durham and Whitley 1971).

Of the remaining species listed by Forbes and Richardson (1908) and not included above, the mud darter and bluntnose darter have been taken as recently as 1974 (Price 1975) and probably are still present in the system. The bigeye shiner was last taken in 1967 (Durham and Whitley 1971) and is on the threatened list for Illinois. The bigeye chub, on the endangered list, and the horneyhead chub were last officially reported in the Embarras system by Hankinson (1913). In an unpublished paper, Smith (1940, personal copy) listed the horneyhead chub from the same tributary (Polecat Creek) from which Hankinson collected his specimens. The gravel chub and tadpole madtom were reported only from the Forbes and Richardson study and probably are no longer present in the system.

The blacknose shiner has been extirpated from the Embarras (Smith 1968). The probable cause was the initial drainage of the wet prairies in eastern Illinois. The silver chub was last collected during the 1963 fish kill and seemingly has been extirpated.

The harlequin darter was first found in Illinois by Smith in 1965 (23 specimens in a 32-km stretch of the Embarras in Cumberland and Jasper counties). Price (Lopinot 1967) collected one specimen with rotenone in Jasper County. In 1980, a 5-month study (May–August) was conducted to determine the status of the darter in the river. The same section of the river from which Smith obtained specimens was studied (Durham 1980). No harlequin darters were found after hundreds of seine hauls and electrofishing using electric seines and boat-shocking. Conditions were such that the darter should have been collected if present. (Nine other species of darters were among the 48 species of fish taken). In 1983, one specimen was taken about 100 m below the Lake Charleston spillway in Coles County. One additional specimen was identified the following year from the same region. After the collapse of the dam in 1985, one specimen was collected (H. L. Bart, University of Illinois, personal communication). Since reconstruction of the dam, none has been found. The harlequin darter is on the Illinois endangered list.

In addition to the bigeye chub and harlequin darter, the eastern sand darter is also on the Illinois endangered list. It was collected as recently as 1987 at four mainstem stations (Ettinger 1989).

The Ohio lamprey was reported by Hubbs and Trautman (1937) from the Embarras at two localities but does not now occur in Illinois. The report may have been the result of a misidentification of the closely related chestnut lamprey (Smith 1968).

Price (Lopinot 1962) reported the mimic shiner, stonecat, and mooneye from the Embarras basin. The mimic shiner and stonecat were also reported

Table 8. Fish species reported in 11 studies made of the Embarras River. (X indicates the presence of the species in the report.) Scientific names in Table 9.

Species	1908 Forbes and Richardson	1913 Hankinson	1963 Larimore and and Smith	1962 Lopinot (Price)	1967 Lopinot (Price)	1967–70 Durham and Whitley	1970–72 Buth	1974 Price	1978 Smith	1987 Ettinger	1987–88 Osborne
	Year of collection and reference										
Grass pickerel	X	X	X	X	X	X	X	X	X	X	X
Creek chub	X	X	X	X	X	X	X	X	X	X	X
Golden shiner	X	X	X	X	X	X	X	X	X	X	X
Striped shiner	X	X	X	X	X	X	X	X	X	X	X
Sand shiner	X	X	X	X	X	X	X	X	X	X	X
Redfin shiner	X	X	X	X	X	X	X	X	X	X	X
Spotfin shiner	X	X	X	X	X	X	X	X	X	X	X
Silverjaw minnow	X	X	X	X	X	X	X	X	X	X	X
Bluntnose minnow	X	X	X	X	X	X	X	X	X	X	X
Stoneroller	X	X	X	X	X	X	X	X	X	X	X
Spotted sucker	X	X	X	X	X	X	X	X	X	X	X
White sucker	X	X	X	X	X	X	X	X	X	X	X
Creek chubsucker	X	X	X	X	X	X	X	X	X	X	X
Black bullhead	X	X	X	X	X	X	X	X	X	X	X
Yellow bullhead	X	X	X	X	X	X	X	X	X	X	X
Blackstripe topminnow	X	X	X	X	X	X	X	X	X	X	X
Bluegill	X	X	X	X	X	X	X	X	X	X	X
Green sunfish	X	X	X	X	X	X	X	X	X	X	X
Longear sunfish	X	X	X	X	X	X	X	X	X	X	X
Johnny darter	X	X	X	X	X	X	X	X	X	X	X
Suckermouth minnow	X	X	X	X	X	X	X	X	X	X	
Brindled madtom	X	X	X	X	X	X		X	X	X	X
Steelcolor shiner	X	X	X	X	X	X		X	X	X	X
Bullhead minnow	X	X		X	X	X		X	X	X	
Golden redhorse	X	X	X	X	X	X		X	X	X	X
Northern hogsucker	X	X	X	X	X	X		X	X	X	X
Channel catfish	X	X	X	X	X	X		X	X	X	X
Spotted bass	X	X	X	X	X	X		X	X	X	X
Largemouth bass	X	X		X	X	X	X	X	X	X	
Blackside darter	X	X	X	X	X	X		X	X	X	X
Slenderhead darter	X	X		X	X	X		X	X	X	X
Greenside darter	X	X	X	X	X	X		X	X	X	X
Rainbow darter	X	X	X	X	X	X		X	X	X	X
Logperch	X	X	X	X	X	X		X	X	X	X

Table 8. *Continued.*

Species	1908 Forbes and Richardson	1913 Hankinson	1963 Larimore and and Smith	1962 Lopinot (Price)	1967 Lopinot (Price)	1967–70 Durham and Whitley	1970–72 Buth	1974 Price	1978 Smith	1987 Ettinger	1987–88 Osborne
	Year of collection and reference										
Silvery minnow	X	X		X	X	X		X	X	X	
Orangespotted sunfish	X		X	X	X		X	X	X	X	
Emerald shiner	X	X	X		X	X		X	X	X	
Fathead minnow	X	X			X	X			X	X	X
Brook silverside	X	X			X	X			X	X	
White crappie	X	X		X		X	X	X	X	X	
Black crappie	X	X		X		X		X	X	X	
Fantail darter	X	X		X	X	X			X	X	
Pirate perch	X		X	X		X	X	X	X	X	X
Highfin carpsucker	X	X			X	X			X	X	
Eastern sand darter	X	X				X			X	X	
Shorthead redhorse	X	X			X	X		X	X	X	
Gizzard shad		X	X	X	X	X	X	X	X	X	X
Common carp		X	X	X	X	X	X	X	X	X	X
Bigmouth buffalo		X			X	X		X	X	X	
Flathead catfish		X		X		X		X	X	X	
Freckled madtom		X		X		X		X	X	X	
Dusky darter	X			X	X		X	X	X		
Slough darter		X			X	X	X	X	X	X	
Silver redhorse		X				X		X	X	X	
Warmouth		X			X	X		X	X	X	
Smallmouth bass	X	X				X			X		
Sauger	X				X	X		X	X		
Bigeye shiner	X	X		X		X			X		
Bigeye chub	X	X							X		X
Horneyhead chub	X	X							X		
Mud darter	X	X			X	X			X		
Gravel chub	X								X		
River shiner	X								X	X	
Tadpole madtom	X								X		
Bluntnose darter	X					X		X	X		
American eel		X	X			X			X		
Goldeye		X				X		X	X		
Bowfin		X				X		X			
Black buffalo		X				X		X	X		
Smallmouth buffalo		X				X		X			

Table 8. *Continued.*

	Year of collection and reference										
Species	1908 Forbes and Richardson	1913 Hankinson	1963 Larimore and and Smith	1962 Lopinot (Price)	1967 Lopinot (Price)	1967–70 Durham and Whitley	1970–72 Buth	1974 Price	1978 Smith	1987 Ettinger	1987–88 Osborne
Rock bass		X		X		X		X	X		
Silver chub		X				X			X		
Orangethroat darter			X		X	X		X	X	X	
River carpsucker					X	X			X	X	
Quillback		X			X	X	X	X	X	X	X
Mosquitofish				X	X			X	X	X	
River carpsucker					X	X			X	X	
Quillback	X			X	X	X	X	X	X	X	
Mosquitofish				X	X			X	X	X	
Freshwater drum					X	X		X	X		
Longnose gar						X		X	X		
Amereric brook lamprey						X			X	X	
Yellow bass					X	X			X		
Skipjack herring						(1976)		X	X		
Northern pike						(1976)	X		X		
Harlequin darter					X	(1983)			X		
Ribbon shiner				X	X			X	X		X
Mountain madtom					X	(1980)			X	X	
Shortnose gar						X		X			
Mimic shiner				X					X		
Stonecat				X					X		
Mooneye				X							
Chestnut lamprey						X					
Paddlefish						X					
Grass carp						(1978)					
White bass						(1982)					
Silver carp						(1986)					
Silver lamprey						(1980)			X	X	
Red shiner								X			
Spottail darter								X			
Ohio lamprey									X		
Black redhorse											X
Pugnose minnow								X			
Blacknose shiner									X		
Total species:	56	58+ 6 hypoth.	38	52	59	76+ 8 later	30	67	88	63	37

Table 9. Fish species reported from the Embarras River system.

Family Scientific name	Common name
Petromyzontidae	
Ichthyomyzon bdellium (Jordan)	Ohio lamprey
I. castaneus Girard	Chestnut lamprey
I. unicuspis Hubbs & Trautman	Silver lamprey
Lampetra appendix (DeKay)	American brook lamprey
Polyodontidae	
Polyodon spatula (Walbaum)	Paddlefish
Lepisosteidae	
Lepisosteus osseus (Linnaeus)	Longnose gar
L. platostomus (Rafinesque)	Shortnose gar
Amiidae	
Amia calva (Linnaeus)	Bowfin
Hiodontidae	
Hiodon alosoides (Rafinesque)	Goldeye
H. tergisus (Lesueur)	Mooneye
Anguillidae	
Anguilla rostrata (Lesueur)	American eel
Clupeidae	
Dorosoma cepedianum (Lesueur)	Gizzard shad
Alosa chrysochloris (Rafinesque)	Skipjack herring
Cyprinidae	
Campostoma anomalum (Rafinesque)	Central Stoneroller
Ctenopharyngodon idella (Valenciennes)	Grass carp
Cyprinella lutrensis (Baird & Girard)	Red shiner
C. spilopterus (Cope)	Spotfin shiner
C. whipplei (Girard)	Steelcolor shiner
Cyprinus carpio Linnaeus	Common carp
Erimystax x-punctata Hubbs & Crowe	Gravel chub
Hybognathus nuchalis Agassiz	Mississippi silvery minnow
Hypophthalmichthys molitrix	Silver Carp
Luxilus chrysocephalus (Rafinesque)	Striped shiner
Lythrurus fumeus Evermann	Ribbon shiner
L. umbratilis (Girard)	Redfin shiner
Macrhybopsis storeriana (Kirtland)	Silver chub
Nocomis biguttatus (Kirtland)	Horneyhead chub
Notemigonus crysoleucas (Mitchell)	Golden shiner
Notropis amblops (Rafinesque)	Bigeye chub
N. atherinoides Rafinesque	Emerald shiner
N. blennius (Girard)	River shiner
N. boops Gilbert	Bigeye shiner
N. heterolepis Eigenmann & Eigenmann	Blacknose shiner
N. buccatus Cope	Silverjaw minnow
N. stramineus (Cope)	Sand shiner
N. volucellus (Cope)	Mimic shiner
Opsopoeodus emeliae (Hay)	Pugnose minnow
Phenacobius mirabilis (Girard)	Suckermouth minnow
Pimephales notatus (Rafinesque)	Bluntnose minnow
P. promelas Refinesque	Fathead minnow
P. vigilax (Baird & Girard)	Bullhead minnow
Semotilus atromaculatus (Mitchell)	Creek chub
Catostomidae	
Ictiobus bubalus (Rafinesque)	Smallmouth buffalo
I. cyprinellus (Valenciennes)	Bigmouth buffalo
I. niger (Rafinesque)	Black buffalo
Carpiodes carpio (Rafinesque)	River carpsucker

Table 9. *Continued.*

Family Scientific name	Common name
C. cyprinus (Lesueur)	Quillback
C. velifer (Rafinesque)	Highfin carpsucker
Moxostoma anisurum (Rafinesque)	Silver redhorse
M. duquesnei (Lesueur)	Black redhorse
M. erythrurum (Rafinesque)	Golden redhorse
M. macrolepidotum (Lesueur)	Shorthead redhorse
Hypentelium nigricans (Lesueur)	Northern hog sucker
Catostomus commersoni (Lacepede)	White sucker
Minytrema melanops (Rafinesque)	Spotted sucker
Erimyzon oblongus (Mitchill)	Creek chubsucker
Ictaluridae	
Ameiurus melas (Rafinesque)	Black bullhead
A. natalis (Lesueur)	Yellow bullhead
Ictalurus punctatus (Rafinesque)	Channel catfish
Pylodictis olivaris (Rafinesque)	Flathead catfish
Noturus eleutherus Jordan	Mountain madtom
N. flavus Rafinesque	Stonecat
N. gyrinus (Mitchell)	Tadpole madtom
N. miurus (Jordan)	Brindled madtom
N. nocturnus Jordan & Gilbert	Freckled madtom
Esocidae	
Esox americanus vermiculatus Gmelin	Grass pickerel
E. lucius Linnaeus	Northern pike
Aphredoderidae	
Aphredoderus sayanus (Gilliams)	Pirate perch
Cyprinodontidae	
Fundulus notatus (Rafinesque)	Blackstripe topminnow
Poeciliidae	
Gambusia affinis (Baird & Girard)	Western mosquitofish
Atherinidae	
Labidesthes sicculus (Cope)	Brook silverside
Percichthyidae	
Morone chrysops (Rafinesque)	White bass
M. mississippiensis Jordan & Eigenmann	Yellow bass
Centrarchidae	
Micropterus dolomieui Lacepede	Smallmouth bass
M. punctulatus (Rafinesque)	Spotted bass
M. salmoides (Lacepede)	Largemouth bass
Lepomis cyanellus Rafinesque	Green sunfish
L. gulosus (Cuvier)	Warmouth
L. humilis (Girard)	Orangespotted sunfish
L. macrochirus Rafinesque	Bluegill
L. megalotis (Rafinesque)	Longear sunfish
L. microlophus (Gunther)	Redear sunfish
Ambloplites rupestris (Rafinesque)	Rock bass
Pomoxis annularis Rafinesque	White crappie
P. nigromaculatus (Lesueur)	Black crappie
Percidae	
Stizostedion canadense (Smith)	Sauger
Percina caprodes (Rafinesque)	Logperch
P. maculata (Girard)	Blackside darter
P. phoxocephala (Nelson)	Slenderhead darter
P. sciera (Swain)	Dusky darter
Ammocrypta pellucida (Putnam)	Eastern sand darter
Etheostoma asprigene (Forbes)	Mud darter

Table 9. *Continued.*

Family Scientific name	Common name
E. blennioides Rafinesque	Greenside darter
E. caeruleum Storer	Rainbow darter
E. chlorosomum (Hay)	Bluntnose darter
E. flabellare Rafinesque	Fantail darter
E. gracile (Girard)	Slough darter
E. histrio Jordan & Gilbert	Harlequin darter
E. nigrum Rafinesque	Johnny darter
E. spectabile (Agassiz)	Orangethroat darter
Sciaenidae	
Aplodinotus grunniens Rafinesque	Freshwater drum

in 1967. In 1974, he reported the red shiner and spottail darter. No other records seem to be available for these two species in the Embarras.

Durham and Whitley (1971) reported the chestnut lamprey and paddlefish. Later collections included the grass carp (1978), white bass (1982), and silver carp (1986). These were new records for the Embarras.

Osborne et al. (1991) were the first to report the black redhorse in the Embarras. This is not the normal range of this species, but the report was verified (R. W. Larimore, Illinois Natural History Survey, personal communication).

Smith's (1978) *The Fishes of Illinois* lists 88 species of fish for the Embarras (based on his distribution maps). One species, the pugnose minnow, was not collected in the other studies reviewed in this paper. He did not include the following species, which were reported in the reviewed studies:

Bowfin	Chestnut lamprey
White bass	Smallmouth buffalo
Paddlefish	Red shiner
Shortnose gar	Grass carp
Spottail darter	Mooneye
Silver carp	Black redhorse

I have verified the identification of the bowfin, smallmouth buffalo, shortnose gar, chestnut lamprey, paddlefish, grass carp, silver carp, and white bass.

Smith (1971) described the Embarras, particularly the reach between Charleston and Newton, as having an excellent variety of habitats and extremely rich species diversity. He considered the middle section of the river to be one of the outstanding streams in Illinois. Because of the variety of habitats, at least 101 species have been recorded from the system, including several that are rare or limited elsewhere in the state. These included the harlequin darter, dusky darter, eastern sand darter, spotted bass, mountain madtom, and greenside darter.

Based on the above findings, 89 species (of the 101 total) could be expected to be found in the river at the present time. Those not expected to be found include the following:

Ohio lamprey—probable error in identification;

Bigeye shiner—last reported in 1967 (threatened species);

Bigeye chub—last reported in 1913 (endangered);

Horney head chub—last reported officially in 1913;

Gravel chub—last reported in 1908;

Tadpole madtom—last reported in 1908;

Blacknose shiner—reported as extirpated, Smith (1968); and

Silver chub—last reported in fish kill, 1963.

Normal distribution records of the following species would question their reported presence in the river: mooneye, red shiner, spottail darter, and possibly pugnose minnow.

Seven species were probably extirpated from the river, and five species may have been reported erroneously. Whatever caused the demise of the seven species, it occurred some time ago, probably around the turn of the century. Major river alterations by that time included wetland drainage, a great increase in agriculture, and some channelization.

Smith (1968) discussed changes in the fish fauna of the Embarras up to 1966. He listed 20 species that no longer occurred in parts of the river basin where they occurred before 1901. Rea-

sons given were (1) alteration of the physical habitat (e.g., rate of flow, bottom type), nine species; (2) increase in amount of suspended silt and subsequent loss of aquatic vegetation, six species; and (3) reduction in stream size, three species. Reasons were not given for the remaining two species. Smith indicated that while pollution undoubtedly contributed to the demise of some species, its effects are often much less dramatic and even difficult to discern.

Ettinger (1989) used the Index of Biotic Integrity (Karr et al. 1986) to determine the rating of the aquatic resource on the mainstem and 10 tributaries. The IBI incorporates data from the study of entire fish communities into 12 metrics in three categories. The top rating possible is 60, with 58–60 excellent, 48–52 good, 40–44 fair, 28–34 poor, and 12–22 very poor. Values on the mainstem ranged from a low of 28 at Billett to a high of 50 below Lake Charleston dam. The mean for all mainstem stations was 38, placing the Embarras River in the moderate aquatic resource category. Only three stations on the Embarras were rated as highly valued, and all were in the middle section of the river below Lake Charleston and above Ste. Marie. (Billett was rated as a limited aquatic resource.)

With only three major dischargers in the basin and no known industrial or nonpoint problems, the average IBI for the mainstem seems to be lower than expected, particularly in light of Smith's (1971) statement that the middle section of the Embarras is one of the outstanding streams in Illinois. Several factors may have depressed the observed IBI's: excessive stream width, particularly below Lake Charleston, may have allowed fish to escape around the electric seine; pools too deep for adequate sampling with the seine, along with reduced visibility caused by disturbed silt; a large percentage of sand (41%) at the mainstem stations; and too few sampling attempts at each station for an adequate IBI analysis.

The studies in Cumberland and Jasper counties (Durham 1980) showed 48 fish species, including nine darters. In Coles County studies, Durham and Whitley reported 76 species (plus eight later on). The middle segment of the river is indeed outstanding.

The IBI values for the tributaries ranged from a low of 32 on Indian Creek near Lawrenceville and Scattering Fork near Camargo to a high of 50 on Riley Creek near Charleston. The average for the 10 tributaries was 41. Four of the 10 sites were rated as moderate aquatic resources, while the remaining six stations were highly valued aquatic resources.

Commercial Fishing

In a report on commercial fishing in Illinois rivers for 1950 (Starrett and Parr 1950), the Embarras River was listed as producing 1,700 kg of commercial fishes (carps—55.2%, buffalofishes—29.8%, catfishes—14.2%, bullheads—0.8%) with a value of $311.71. Most were taken with hoopnets (1,513 kg); the remainder (181 kg) were taken in basket traps (catfishes and bullheads). Only six part-time fishermen accounted for the above catches.

By definition, a professional commercial fisherman was a person purchasing tags or licenses for five or more nets (Lopinot 1962). Most of such activity occurred in Lawrence County, although almost the entire river is open to commercial fishing. The exception is from the Route 130 bridge in Coles County (below the Lake Charleston dam) upstream to Route 16, including Lake Charleston. This segment is designated as a fish preserve.

Price (Lopinot 1962) indicated that after 1950, for all practical purposes, commercial fishing was nonexistent. Restrictions on the use of commercial equipment have been established because of conflicts between handline fishermen and those using such commercial gear. No data are available to state that commercial activities at such low levels are detrimental to handline fishermen.

Sport Fishing

From Douglas County south, the Embarras River receives moderate to heavy sport fishing pressure by local residents. Lake Charleston, recently refurbished and stocked regularly with catfish, hybrid striped bass, and others receives fairly heavy fishing pressure, particularly in late spring and fall. The lower reaches of the river receive the heaviest fishing.

Most of the length of the river is fished. Particularly sought after species include channel catfish, flathead catfish, common carp, spotted bass, largemouth bass, smallmouth bass, crappies, sauger, and a variety of sunfish. Public access is often a problem because of private ownership of the surrounding lands. Some public boat ramps have been provided recently through state and federal programs, but more are needed.

Future of the River

The Embarras River has undergone a number of physical changes in the past. Draining of wetlands, channelization, dredging, improper agricultural practices, growth of villages and cities along the watercourse, and the one dam have left their mark. Chemical spills, discharges from municipalities, oil field wastes, and nonpoint source agricultural runoff have affected the river at various times.

In spite of these factors the Embarras River is in relatively good condition. As more stringent regulations have been adopted with respect to dredging, channelization, chemical discharges, and waste treatment, the river has responded positively. As additional regulations are adopted and present ones are refined and enforced, further improvements can be expected.

The location of the river in mainly rural areas has caused fewer problems than might have resulted from a more urban location and is a major factor in determining its good condition. This rural situation has resulted, however, in the main problem affecting the river, which is the heavy silt load that it sometimes carries. In the many years that I have observed the river, it has become an expected occurrence that when heavy rain falls in Champaign or Douglas County, the rich black soil from those areas soon will be passing by Coles County in the dark, muddy-appearing water. This situation has improved considerably in recent years, probably due to better soil conservation practices upstream and to greater awareness of the need to save the topsoil. Much more of both is needed.

The problems with oilfield pollution should eventually ease as production decreases. However, pressure should be exerted to correct as much of the problem as possible. Further improvements in wastewater treatment plants are needed in some areas. This is particularly true in the Oblong area, based on the Ettinger (1989) study.

As urban areas continue to expand in population and area, they will have a greater effect on the Embarras system. To minimize this, sufficient sanitary and stormwater sewers, along with proper treatment facilities, should be required to handle the expansion. Prevention of developments in floodplain areas should be legislated and enforced. Shoreline protection would help reduce the siltation problem.

Long-range plans still exist for possible dam sites on the river (Illinois Department of Conservation 1947). As water supply problems develop and as the demand for aquatic recreational areas and flood control projects increases, pressure will be exerted to develop such dam sites. As mentioned previously, one such effort was defeated in the late 1960's and early 1970's. Resistance to such developments should be continued.

As public access facilities increase along the waterway, additional effects will result. Through proper regulation, these can be minimized. The Embarras River system is small enough that it could be well-managed with a little effort. A concerted effort to create some kind of regulatory body would ensure that the present scenic, recreational, and ecological values are maintained or enhanced.

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The Kankakee River: A Case Study and Management Recommendations for a Stream Diverse in Habitat, Fauna, and Human Values

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Abstract. The Kankakee River of northern Illinois and Indiana is known for its diversity in habitat and fauna, as well as human values. The basin was once part of a vast wet prairie called the Grand Marsh, until the early 1900's, when most of the main river in Indiana was channelized and much of this wetland was drained. The Illinois portion of the river has remained naturally flowing except for two low-head dams. The conditions created by the complex geology and geomorphology of the basin support great faunal diversity. Ninety-nine fish species, 35 mussel species, and a diverse array of benthic macroinvertebrates occur in the river basin, including a number of endangered, threatened, and rare species. Assessments have demonstrated that the water quality, habitat, and fauna of the river are highly vulnerable to sedimentation, pollution, changes in flow regime, and other human impacts. Regardless of this knowledge, numerous channel and watershed modification and development projects have been proposed for the river. Interstate differences in habitat and biota, along with conflicting human perceptions and goals, have impeded effective management of the river basin in the past. The following measures are recommended for protection and enhancement of this unique river resource: (1) restrict and minimize channelization, clearing, and construction on the river, floodplain, and feeder streams; (2) protect remaining riparian habitat from development, especially forested floodplain and wetlands; (3) modify land-use practices, primarily agricultural, to reduce levels of siltation and pollution; (4) determine and protect critical minimum flows within the basin; (5) apply and evaluate river restoration techniques to stabilize banks and restore portions of the river channel to a natural flow pattern; and (6) integrate protection and enhancement into a holistic, basinwide management plan.

The Kankakee River basin was once part of a vast productive wet prairie called the Grand Marsh. By 1918, however, most of the main river in Indiana was channelized, and much of this expansive wetland was drained. Nonetheless, the Kankakee River is known for its diversity in habitat and fauna—and human values. A profound demarcation in all these may be found at the Illinois-Indiana state line.

The Kankakee River flows southwest into Illinois from its source in northern Indiana and further westward to its confluence with the Des Plaines River, forming the Illinois River (Fig. 1). The Kankakee River is 241 km long and drains an area of 13,377 km^2 (Ivens et al. 1981). Most of the river lies upstream in Indiana (146 km length and 7,760 km^2 drainage area), where it is primarily managed as an agricultural drainage project and

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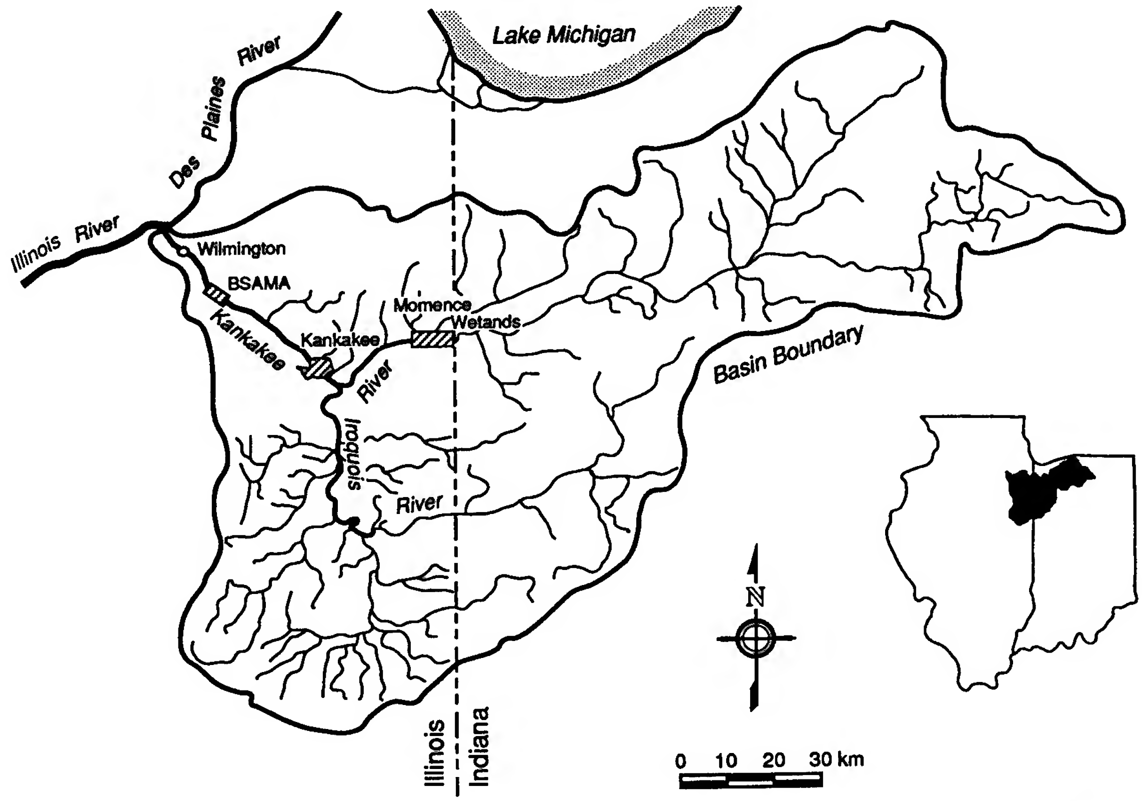

Fig. 1. Map of the Kankakee River basin of northern Illinois and Indiana (BSAMA = Braidwood Station Aquatic Monitoring Area).

wetlands have been converted to productive agricultural land. Conversely, the Illinois portion of the river meanders naturally and is valued for its scenic, cultural, and recreational resources (Fig. 2). Interstate differences in physical attributes and biota of the river, along with conflicting human perceptions and goals, have impeded effective management of the Kankakee River basin.

The high quality of the Kankakee River and its aquatic life has been declared in several categorical ratings by investigators over the years. Smith (1971) rated the river as "excellent" among Illinois streams, based on its diverse fish assemblages. The Biological Stream Characterization (Hite and Bertrand 1989), a biological assessment of Illinois stream quality using fish and macroinvertebrate populations, water quality, sediment chemistry, and habitat quality as criteria, classified most of the Kankakee River as a "Class B" stream (Highly Valued Aquatic Resource). The Kankakee River was also included on a list of outstanding Illinois aquatic ecosystems, compiled by Page et al. (1989), and was appraised to be in "excellent condition" based on the uniqueness of its fauna and environmental quality. In addition, that list identified high fish and mussel diversity in the Kankakee River, and it ranked the stream third in the state among those deserving protection. Evaluation of the fish assemblages occurring in the Indiana portions of the river led to "good" ratings for most of the examined reaches (Smith 1981).

Several factors threaten the quality of the Kankakee River environment and its biota; among these are siltation, drainage of wetlands in the watershed and channelization, low flows and water temperature elevation, and water pollution (Smith 1971; Ivens et al. 1981; Page et al. 1989). The differences in perceptions, values, and goals between the stewards of the river in Indiana and Illinois have led to a series of unresolved conflicts, usually leading to the courtroom, with no realistic compromise in sight. The aim of this report is to provide a history and status of the habitat and biota of the Kankakee River basin, qualify its value, suggest measures for protection and enhancement of the ecosystem, and serve as a starting point in development of a holistic, basinwide management plan.

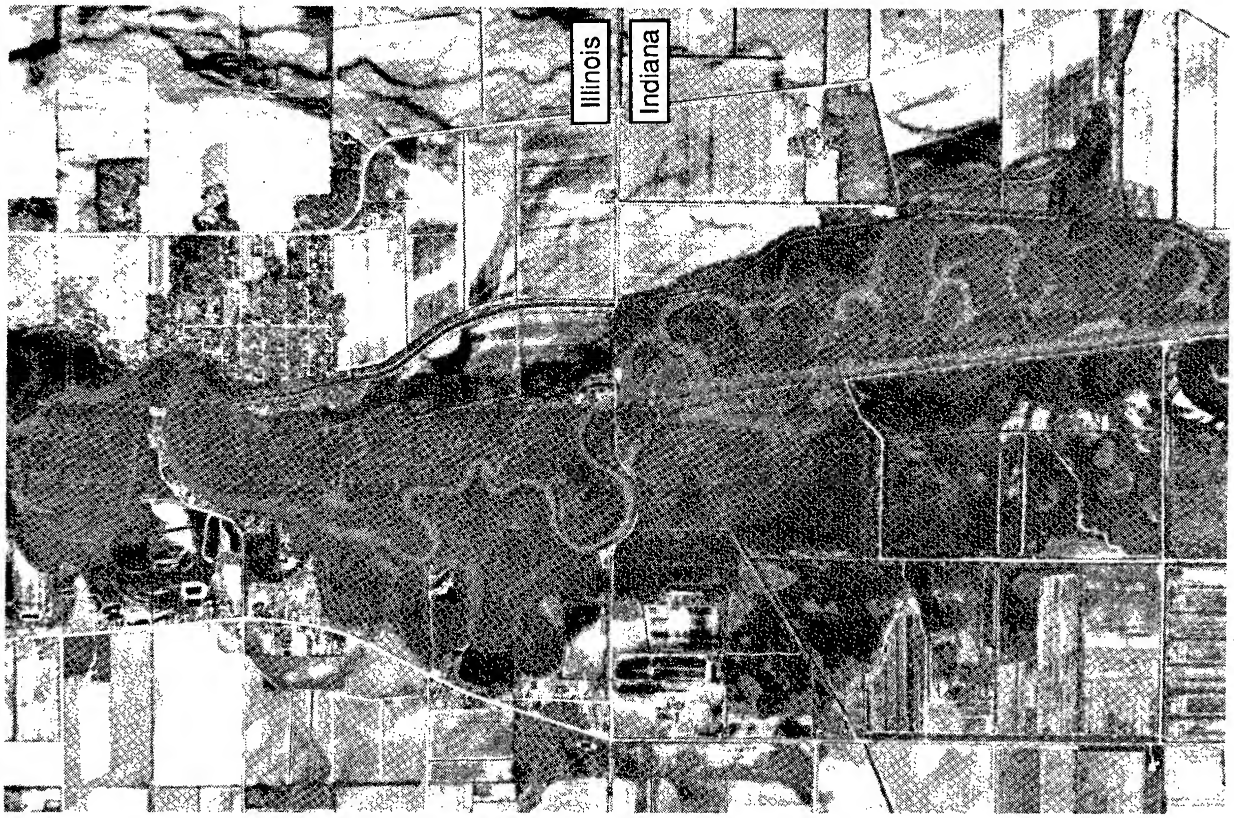

Fig. 2. Aerial photograph of the Kankakee River as it crosses the Illinois–Indiana state line, taken on 12 April 1988. *Photograph courtesy of the Illinois Department of Transportation.*

Historical Background

The history of human activities in the Kankakee River basin is rich and full and is a crucial part of understanding the river today. The early transformation of the basin from a haven of wildlife into a modern home for man was described by Meyer (1936) as four stages of European settlement: (1) the period of the American Indian hunter and French trader (pre-1840), (2) immigration of the pioneer trapper and farmer (1840–80), (3) the epoch of the rancher and sportsman fowler (1880–1910), and (4) joint occupancy by the farmer and river resorter (post-1910). The first two stages are characterized as human adjustment *to* the environment, whereas the final period may be portrayed as human adjustment *of* the environment.

French explorers entered the Kankakee River in the late 17th century. Soon after, other European trappers and traders followed and coexisted with the Pottawatomie American Indian, living similar lifestyles on the islands and margins of the Grand Marsh. The Pottawatomie found the marsh a bountiful hunting ground and an effective refuge from their enemies, the Iroquois. American Indian occupation of the area came to a close with the treaties of 1832 and 1836, and was followed by an influx of Europeans that hunted and trapped during winter and ranched and farmed the uplands and marsh margins during summer.

By the late 1800's, some forms of animal life were already becoming scarce (e.g., the last deer was reported shot in 1880), but fish and wildfowl remained abundant as this hunter's and fisherman's paradise provided a strong recreation industry and commercial harvest of wildlife for markets in Chicago and New York. Even this potential overharvest of resources did not have such a lasting and irreversible effect as did the efforts of those who began "reclamation" of the area by draining the marsh and lowlands.

The later stages of watershed modification were detailed by Bhowmik and Bonini (1981) and Ivens et al. (1981), documenting a series of conflicting and disjunct management plans and actions. Limited marshland drainage facilitated road and railroad construction, and soon the natural industries of the area (e.g., lumbering, marsh haying and grazing, market hunting and trapping) gave way to grain and livestock farms. Ditch digging began by hand and was later accelerated by use of steam dredges and the formation of drainage districts. Singleton

Ditch in Indiana and several other large drainage ditches were constructed around 1866, but these efforts were only partially successful in their goal. Several studies during the late 1800's concluded that modification of the Kankakee River for navigation could not be a cost-effective venture, but other channel and backwater alterations to improve drainage were recommended and continued (Ivens et al. 1981).

In 1893, the State of Indiana financed a futile attempt at removing a portion of a broad limestone ledge near Momence, Illinois, which was believed to be an obstacle to upriver drainage. A shallow, 2.4-km channel was excavated in the rock ledge with at least 4 km remaining intact. The project was deemed a failure, and Illinois resisted further modifications to the ledge. The rock outcrop at Momence continues to impound water, forming a productive wetland area dominated by floodplain forest called the Momence Wetlands (Mitsch et al. 1979).

In Indiana, channelization continued and was essentially completed by 1918. The upstream meandering channel of 400 km was straightened to form a 130-km ditch. The Grand Marsh was "reclaimed," and drainage efforts were focused on channelization of tributaries and levee construction to contain floodwaters. Downstream in Illinois, the river has remained in its natural form, except for the modification of the rock outcrop near Momence and the construction of two low-head dams at Kankakee and Wilmington.

The draining of the Grand Marsh has not been without its opposition and its subsequent consequences. Although over 400,000 ha of land were affected by improved drainage, the flooding problem was not solved; severe flooding still occurred over the watershed, particularly upstream of Momence. Forbes and Richardson (1920) noted that "the water flows off much sooner after it falls, and consequently the river is higher during the autumn and spring floods and lower at other seasons than formerly." The severe peak floods prompted numerous studies and proposals for channel modification in Illinois, but intense objection by conservation and environmental groups, high estimated cost to benefit ratios, and lack of funds prevented action. Other investigations (in 1931 and 1941; Ivens et al. 1981) demonstrated that large quantities of sand had been deposited in Illinois from upstream channel erosion in Indiana, but that the rate was decreasing.

As recently as 1979, a plan was drafted in Indiana that included clearing debris and snag removal in the channel and modification of levees along the banks (SEG Engineers and Consultants, Inc. 1989). The State of Illinois opposed the project on the grounds that it would increase floodwater velocities, as well as sand and sediment load, and would destroy aquatic life and private property. Public concern led to a detailed study of the geology, hydrology and sediment transport, and effects of sedimentation on aquatic life in the Kankakee River (Bhowmik et al. 1980; Brigham et al. 1981; Gross and Berg 1981; Ivens et al. 1981). Recommendations from this study were to avoid all dredging, clearing, or construction on the river and to concentrate efforts on improving the surrounding land to reduce sedimentation through preventative measures. Suggested actions included improving land-use practices, proper maintenance of existing ditches and levees, minimal disturbance to the mainstem river, and mitigation during necessary construction.

A federal court ruled that the proposed river modifications in Indiana required a permit from the U.S. Army Corps of Engineers, which was denied in 1983. During that same year, Indiana began installation of a system of wide levees along the river to further restrict the river's flow. The stated goals of this project were "to provide flood protection and enhance agricultural drainage" (SEG Engineers and Consultants, Inc. 1989).

The Physical Environment

Geology and Geomorphology

The general geomorphology of the Kankakee River basin was established during the melting of the last continental glaciers, when numerous moraines were formed 13,000 to 16,000 years ago (Gross and Berg 1981). After the melting, vast sand dunes appeared, which continue to migrate westward. The underlying bedrock in the basin is made up primarily of Devonian shale and Silurian dolomite. Most of the soil in the basin in Indiana is composed of sand, but the landscape in Illinois is more complex. Surface materials in Illinois include silt and clay glacial tills, lacustrine sediment, exposed bedrock, and sand.

The present form of the river in Indiana is a direct result of channelization, dredging, and other artificial modifications of the past (Gross and Berg 1981; Ivens et al. 1981). Recent surveil-

lance revealed that, unlike many other channelized streams, the morphology of the Kankakee River in Indiana seems to have remained relatively unchanged since its modification (i.e., the channel has not begun to meander). Much of the river in Illinois flows through sand deposits overlying bedrock, and deep sand bars along the channel are common. The river channel in Illinois upstream of Momence meanders through thick sand deposits and resembles the river in Indiana before its channelization (Fig. 2). Most of the river downstream of Momence flows over bedrock, except for an impounded area near the city of Kankakee, where thick deposits of sand are found.

The long-held contention that dredging of the Kankakee River in Indiana has caused increased sedimentation and sand choking downstream in the natural Illinois portion of the river prompted a detailed time-series analysis of aerial photographs of the river (Gross and Berg 1981). Aerial photos between 1939 and 1954 revealed increasing sedimentation in the form of accretion of beaches and islands in the Kankakee River in Illinois. This deposition was evident upstream of the confluence of the Iroquois River and the Kankakee River and was greatest at the confluence (Fig. 1). Downstream reaches did not seem to be affected. Subsequent aerial photos (1961 and 1973) showed no significant changes in channel morphology, indicating that the river channel had stabilized after 1954 and probably remains in a state of relative equilibrium.

Hydrology

The average discharge of the Kankakee River near its mouth from 1916 to 1979 was 115.8 m^3/s with an average annual peak flow of 687.2 m^3/s (Bhowmik et al. 1980). Trends in discharge and sediment load in the Kankakee River have been summarized in recent studies (Bhowmik et al. 1980; Bhowmik and Bogner 1981; Ivens et al. 1981). Annual peak flows and average flows at several gaging stations in the river have shown an increasing trend from 1930 through 1979, while low-flow volumes have shown no trend. Discharge at Momence, Illinois, a portion of the river that receives most of its flow from Indiana, showed increases in both mean and peak flow rates. An analysis of precipitation data for the upstream portion of the watershed found that no corresponding increases in precipitation occurred during the study period, indicating that factors related to human activity are responsible for the observed changes in discharge over time. Ivens et al. (1981) suggested that clearing natural cover, urban development, decrease in the natural infiltration rate, and changes in the river regime (e.g., channelization), among other factors, may be contributing causes to the trend.

A comparison of daily water discharge and sediment discharge in the Kankakee River indicated that the peaks in the two measures are not always coincidental (Bhowmik at al. 1980). The volume and composition of suspended sediment load were variable; silt and clay were prevalent during low flows, but sandy material made up most of the load during high flows. Movement of materials near the stream bed (bed load) was observed only during flood stages and primarily consisted of sand. A suspended sediment load budget, based on data from 1979 and 1980 for the Illinois portion of the Kankakee River, was developed by Bhowmik and Bogner (1981). The Kankakee River carries an estimated average of 733,000 metric tons of sediment each year, and 70–80% of that is transported during restricted periods during and immediately following storm events (65–85 days/year).

Sediment and Water Quality

The Illinois Environmental Protection Agency rated 88.7% of the Kankakee River as "full support" for aquatic life use, based on water quality monitoring and evaluations (Illinois Environmental Protection Agency 1992). Nutrients and siltation attributable to nonpoint agricultural sources were cited as criteria for the "partial support" rating with minor impairment for the remainder of the stream (11.3%). In addition, all stream segments evaluated for fish consumption and drinking water use were rated as "full support." Thorough analyses of water samples collected from a downstream reach of the river near Wilmington, Illinois, revealed relatively good water quality for most of 45 physical, chemical, and biotic variables measured, but detected concentrations of cadmium, manganese, dieldrin, and polychlorinated biphenyls (PCBs) that exceeded recommended standards (Larimore and Skelly 1981). A review of water quality monitoring data also disclosed occasional observations of iron, copper, lead, and fecal coliform bacteria concentrations that exceeded standards (Beal 1978).

Kankakee River sediments are also relatively unpolluted. Sediment cores from a deep pool near Kankakee, Illinois, were analyzed in detail for 40

elements that indicate the history of chemical enrichment and sedimentation rate (Gross and Berg 1981). The concentrations of trace metals in Kankakee River sediment were lower than those of sediment from all other Illinois waters assessed in a similar manner. Furthermore, in contrast to sediments from other waters, Kankakee River sediment showed no marked increase in chemical enrichment from recent deposits near the top of cores.

The Biota

The aquatic fauna of the Kankakee River has been thoroughly identified in recent surveys (Table 1; Steffeck and Striegl 1989). Most of these surveys have been conducted by the Illinois Natural History Survey to document the diversity in habitat and fauna occurring in the Illinois portion of the river. Detailed surveys of macroinvertebrates, mussels, and fish were conducted during 1978 and 1979 to assess effects of increased sedimentation on aquatic life, as well as to determine the status of rare, threatened, and endangered species (Page et al. 1979; Brigham et al. 1981; Ivens et al. 1981; Suloway 1981).

Another multidisciplinary program of biological investigations and quantitative monitoring on a 2.5-km downstream reach of the Kankakee River was initiated in 1977 by the Illinois Natural History Survey (Larimore and Sule 1978). The purpose of these intensive investigations was to assess potential effects of pumping facilities associated with a nuclear generating station. The study area, known as the Braidwood Station Aquatic Monitoring Area, included 10 river sampling stations and one in a small mainstem tributary. The Braidwood Station Aquatic Monitoring Area is located near Wilmington, Illinois, 23.5 km upstream of the confluence of the Kankakee River with the Des Plaines River (Fig. 1). These investigations spanned 14 years (1977-90, excluding 1980) and yielded a valuable time-series data set on water quality, habitat, and fish assemblages (Peterson 1991; 12 previous annual reports). In addition, the first 4 years of work included detailed investigations of water quality, periphyton, benthic macroinvertebrates, ichthyoplankton, and fish (Larimore and Skelly 1981).

Table 1. Summary of significant recent surveys of the aquatic fauna of the Kankakee River.

Citation	Taxonomic group	Number taxa	Number sites	Number years	Scope: Geographic Intensive	Scope: Geographic Extensive	Scope: Temporal Intensive	Scope: Temporal Extensive
Smith 1971, 1979	Fish	72	60[a]	1		X	X	
Page et al. 1979	Insects	153	13	1		X	X	
	Fish	78	13	1		X	X	
Lewis and Brice 1980	Mussels	20	5	1		X	X	
Brigham et al. 1981	Benthic macroinvertebrates	143	7	1		X	X	
	Mussels	13	7	1		X	X	
	Fish	44	7	1		X	X	
Larimore and Skelly 1981 (and 3 previous annual reports)	Periphyton	99	11	4	X			X
	Benthic macroinvertebrates	163	11	4	X			X
Robertson and Ledet 1981	Fish	48	15	1		X	X	
Suloway 1981	Mussels	20	13	1		X	X	
Sallee et al. 1987	Fish	48	13	1		X	X	
Peterson 1991 (and 12 previous annual reports)	Fish	79	11	13	X			X

[a] Estimated from points on base map.

Despite the above two programs and other recent surveys, aquatic faunal surveys of the Kankakee River have been limited in geographic and temporal scope (Table 1). Surveys are usually conducted over a broad geographic area at a single point in time. The one major exception to this pattern (Braidwood Station Aquatic Monitoring Area) was broad in temporal scope (14 years) but covered a limited sampling area. Quantitative surveys, extensive both in geographic and temporal scope, are required to determine the longitudinal and temporal patterns in biota—information critical to understanding the status of rare species and the ecology of the Kankakee River basin. The known fauna of the Kankakee River includes numerous rare species, relict populations, and species of economic importance; their status and ecology are discussed below.

Benthic Macroinvertebrates

The benthic macroinvertebrate fauna of the Kankakee River is diverse. The precise number of invertebrate species is difficult to ascertain because of the dynamic nature of invertebrate taxonomy and varying levels of specimen identification that occurred in various surveys. Thirteen species of Crustacea are vouchered in the Illinois Natural History Survey Crustacean Collection (Table 2), but comprehensive lists of other aquatic invertebrate specimens (with the exception of mussels) from the drainage are unavailable. Brigham et al. (1981) identified 143 taxa representing over 50 families of benthic macroinvertebrates collected in a survey of seven sites in Illinois over a variety of substrate types. In a survey covering a broader geographic area (13 sites), Page et al. (1979) recorded 27 species of midges (Chironomidae), 62 species of caddisflies (Trichoptera), and 64 species of water beetles (Coleoptera). Ten additional species of caddisflies were previously documented in the river, and 52 more species of beetles are considered likely to occur there, yielding totals of 72 species of caddisflies and 116 species of beetles (Brigham et al. 1981).

Table 2. Aquatic crustaceans recorded from the Kankakee River system. All records are represented by specimens in the Illinois Natural History Survey Crustacean Collection. Data are from Page et al. (1992).

Order	Family	Species
Isopoda	Asellidae	*Caecidotea beattyi*
		C. forbesi
		C. intermedia
		C. kendeighi
Amphipoda	Gammaridae	*Crangonyx gracilis*
		C. minor
		Gammarus pseudolimnaeus
	Hyalellidae	*Hyallela azteca*
Decapoda	Cambaridae	*Cambarus diogenes*
		Orconectes immunis
		O. propinquus
		O. virilis
		Procambarus acutus

Sampling with dredges and artificial substrates in Braidwood Station Aquatic Monitoring Area was conducted quarterly for 3 years (1977–79) followed by a single August collection in 1981 (Larimore and Skelly 1981). Up to 163 benthic macroinvertebrate taxa were collected in a single year. Similar numbers of taxa (mean ± SD) were found in annual summaries of the benthos (154.7 ± 10.4) and colonizing artificial plate samplers (152.0 ± 8.5) in the Kankakee River, but a greater diversity of taxa was collected using artificial substrates (105.5 ± 3.5) compared with benthic grabs (64.3 ± 14.6) in Horse Creek, a mainstem tributary of the Kankakee River in Braidwood Station Aquatic Monitoring Area. The diversity found in artificial substrate samples demonstrates the influence of drift on invertebrate assemblage structure in the basin, particularly in tributary streams.

Taxonomic composition, density, and biomass of macroinvertebrate samples from the Kankakee River at Braidwood Station Aquatic Monitoring Area were highly variable over time and among sampling sites (Larimore and Skelly 1981). Macroinvertebrate samples were dominated, in number and biomass, by aquatic worms (Oligochaeta), bivalve mollusks (Bivalvia), mayflies (Ephemeroptera), and midges (Chironomidae). The taxonomic composition of benthic assemblages in Horse Creek was distinct from that found in the river. The macroinvertebrate fauna of this downstream reach of the river was dominated by collector and scraper functional groups, and predaceous taxa were rare (Larimore and Sule 1980; Merritt and Cummins 1984); both findings are consistent with the River Continuum Concept (Vannote et al. 1980).

Table 3. Mussels (Unionidae) recorded from the Kankakee River system, including protective status (FE = Federally Endangered, FC = Federal Candidate, ILE = Illinois Endangered, ILT = Illinois Threatened, ILC = Illinois Candidate, INE = Indiana Endangered, INSC = Indiana Special Concern). All records are represented by specimens in the Illinois Natural History Survey Mollusk Collection or other museum collections. Data are from Page et al. (1992).

Common name	Scientific name	Protective status
Mucket	*Actinonaias ligamentina*	
Elktoe	*Alasmidonta marginata*	
Slippershell mussel	*A. viridis*	ILE
Threeridge	*Amblema plicata plicata*	
Giant floater	*Anodonta grandis*	
Paper pondshell	*A. imbecillis*	
Cylindrical papershell	*Anodontoides ferussacianus*	
Spectaclecase[a]	*Cumberlandia monodonta*	FC, ILE
Purple wartyback	*Cyclonaias tuberculata*	
Spike	*Elliptio dilatata*	ILC
Snuffbox[a]	*Epioblasma triquetra*	FC, ILE, INE
Ebonyshell	*Fusconaia ebena*	ILC
Wabash pigtoe	*F. flava*	
Plain pocketbook	*Lampsilis cardium*	
Higgins eye[a]	*L. higginsi*	FE, ILE
Fatmucket	*L. siliquoidea*	
White heelsplitter	*Lasmigona complanata complanata*	
Creek heelsplitter	*L. compressa*	ILT
Fluted-shell	*L. costata*	
Fragile papershell	*Leptodea fragilis*	
Black sandshell	*Ligumia recta*	
Washboard	*Megalonaias nervosa*	
Sheepnose	*Plethobasus cyphyus*	ILT, INE
Round pigtoe	*Pleurobema coccineum*	
Pink papershell	*Potamilus ohiensis*	
Monkeyface	*Quadrula metanevra*	
Pimpleback	*Q. pustulosa pustulosa*	
Mapleleaf	*Q. quadrula*	
Salamander mussel	*Simpsonaias ambigua*	FC, ILE, INSC
Squawfoot	*Strophitus undulatus*	
Lilliput	*Toxolasma parvus*	
Pistolgrip	*Tritogonia verrucosa*	
Pondhorn	*Uniomerus tetralasmus*	ILT
Ellipse	*Venustaconcha ellipsiformis*	ILC, INSC
Rainbow[a]	*Villosa iris*	ILE

[a]Denotes species that are probably extirpated from the basin.

Mussels

The freshwater mussels (Unionidae) of the Kankakee River have been studied intermittently since the turn of the century, yielding a list of 35 species in the basin (Table 3). In a recent evaluation of Illinois streams, Page et al. (1992) described the mussels of the Kankakee River as diverse and abundant compared with other Illinois streams, and said they should be regarded as a resource of national importance. Ten species are currently listed with protective status; one is listed as endangered by the U.S. Fish and Wildlife Service, nine are listed by the State of Illinois, and four by Indiana (Illinois Endangered Species Protection Board 1990; Indiana Department of Natural Resources 1990). In addition, three species that currently receive protection at the state level are under consideration for federal protective status, and two additional species have been proposed for listing in Illinois. If all proposals are approved, 12 species of mussels in the Kankakee River will receive some degree of protective status. Unfortunately, Page et al. (1992) noted

that 4 of the 10 listed species have most likely been extirpated from the basin (Table 3).

The mussel fauna of the Kankakee River, like those throughout the eastern United States, has suffered serious declines over the period of record (Lewis and Brice 1980; Brigham et al. 1981; Suloway 1981). A historical review of the Kankakee River mussel fauna indicated a severe reduction at about the turn of the century and a gradual decline thereafter (Suloway 1981). Thirty-two species of mussels were collected in a 1909 survey of 35 sites throughout the Kankakee River basin (Wilson and Clark 1912). Lewis and Brice (1980) recorded 20 species of unionid mussels in the Kankakee River and noted the presence of the introduced Asian clam (*Corbicula fluminea*) in a survey of five Illinois sites during 1976 and 1978. Lewis and Brice (1980) found only a slight reduction in diversity compared with the findings at the same locations by Wilson and Clark (1912), but they noted a recent scarcity of adults of certain species and juveniles. In a longitudinal survey of 13 Illinois sites in 1978, Suloway (1981) also collected 20 species of mussels in the Kankakee River, but noted a significant decline between 1960 and 1978 in the abundance of all species from upstream areas. Nonetheless, twice as many individuals per sample hour were collected in the Kankakee River compared with recent mussel surveys of other Illinois rivers (Brigham et al. 1981).

Fishes

The fish assemblages of the Kankakee River are diverse and abundant, and support a quality sport fishery. Smith (1971) noted the high species diversity that occurred in the varied and unusual habitats of the river and its tributaries. Ninety-nine species of fish representing 19 families have been recorded from the Kankakee River (Table 4). All but 10 of these fishes are represented by voucher specimens in the Illinois Natural History Survey Fish Collection (Page et al. 1992). Seven have protective status in Illinois, and one of these is also listed in Indiana (Illinois Endangered Species Protection Board 1990; Indiana Department of Natural Resources 1990). Introductions of nonnative fishes to the basin have been relatively rare, with only seven presumed introduced species recorded.

Historically, Illinois fishes have received a great deal of attention. The first regional list of fishes was published in 1855 (Kennicott 1855). Two significant collecting programs, one historical and the other recent, provide a clear history of the changes in fish populations and distributions in Illinois waters (Smith 1971). The first program included collections from 1876 to 1905 and culminated in Forbes and Richardson's (1908) landmark publication, *The Fishes of Illinois*, which included six sampling sites in the Kankakee River basin. A second collecting program took place from 1950 to 1971, and included 60 sites in the Kankakee River basin. Smith (1971, 1979) compiled results from both surveys to provide information on the history, changes, and recent status of Illinois fishes. On completion of the 1950–71 program, 72 species of fish were known from the Kankakee River basin (Smith 1971).

Since 1971, several other studies have increased the known number of species and provided insight into distributional and temporal trends among Kankakee River fishes (Table 1; Fig. 3). Page et al. (1979) collected 78 species from 13 locations (29.8 ± 5.5/site, mean ± SD) using electrofishing and seine sampling gears. Recent electrofishing surveys in Illinois (Sallee et al. 1987) and Indiana (Robertson and Ledet 1981) yielded 48 species each. The number of species collected per site was 17.5 (± 4.0) in Illinois and 15.9 (± 4.8) in Indiana. A plot of the number of species collected according to position in the watershed revealed no longitudinal trend in species richness (Fig. 3a), but assemblage structure varied among sites. These surveys indicate that more than one gear is required to adequately sample the fish fauna in this environment.

Thirteen years of fish collections in Braidwood Station Aquatic Monitoring Area, using electrofishing gear and seines with identical sampling equipment and effort each year, have provided an indication of temporal changes in fish assemblages (Peterson 1991; 12 previous annual reports). Seventy-nine species were collected from this 2.5-km reach of stream (Table 4), with an average (± SD) of 50.2 (± 4.3) species/year. Diversity, abundance, and biomass of fishes in the reach have varied widely from 1977 to 1990 (Figs. 3b and 3c). While no increasing or decreasing trend over time was observed in abundance, biomass, or species richness, species diversity had declined over the study period. Peterson (1991) suggested that the decrease in diversity may be attributed to alterations in habitat or water quality in the area caused by upstream influences. Further analyses of these data are warranted to determine the

Table 4. Fishes recorded from the Kankakee River system, including protective status (ILE = Illinois Endangered, ILT = Illinois Threatened, INSC = Indiana Special Concern), origin (N = native, I = Introduced), voucher status [X = specimen(s) deposited in the Illinois Natural History Survey Fish Collection], and fishes found in the sport fishing creel (designated by X) and collected at the Braidwood Station Aquatic Monitoring Area (BSAMA) from 1977 to 1990 (designated by X). Data are primarily from Graham et al. (1984), Peterson (1991), and Page et al. (1992).

Family Species	Protective status	Origin	Voucher status	Present in creel	Collected at BSAMA
Petromyzontidae					
Northern brook lamprey (*Ichthyomyzon fossor*)	ILE	N	X		
Silver lamprey (*I. unicuspis*)		N	X		
American brook lamprey (*Lampetra appendix*)		N	X		
Lepisosteidae					
Longnose gar (*Lepisosteus osseus*)		N		X	X
Amiidae					
Bowfin (*Amia calva*)		N	X	X	X
Anguillidae					
American eel (*Anguilla rostrata*)		N			X
Clupeidae					
Gizzard shad (*Dorosoma cepedianum*)		N	X		X
Threadfin shad (*D. petenense*)		I			X
Cyprinidae					
Central stoneroller (*Campostoma anomalum*)		N	X		X
Largescale stoneroller (*C. oligolepis*)		N	X		
Goldfish (*Carassius auratus*)		I	X		X
Red shiner (*Cyprinella lutrensis*)		N	X		X
Spotfin shiner (*C. spiloptera*)		N	X		X
Steelcolor shiner (*C. whipplei*)		N	X		
Common carp (*Cyprinus carpio*)		I	X	X	X
Striped shiner (*Luxilus chrysocephalus*)		N	X		X
Common shiner (*L. cornutus*)		N	X		
Ribbon shiner (*Lythrurus fumeus*)		N	X		
Redfin shiner (*L. umbratilis*)		N	X		X
Hornyhead chub (*Nocomis biguttatus*)		N	X		X
Golden shiner (*Notemigonus crysoleucas*)		N	X		X
Pallid shiner (*Notropis amnis*)	ILE	N	X		X
Emerald shiner (*N. atherinoides*)		N	X		X
Silverjaw minnow (*N. buccatus*)		N	X		X
Ghost shiner (*N. buchanani*)		N	X		X
Ironcolor shiner (*N. chalybaeus*)	ILT	N	X		
Bigmouth shiner (*N. dorsalis*)		N	X		X
Blacknose shiner (*N. heterolepis*)	ILT	N	X		
Rosyface shiner (*N. rubellus*)		N	X		X
Sand shiner (*N. stramineus*)		N	X		X
Weed shiner (*N. texanus*)	ILE	N	X		
Mimic shiner (*N. volucellus*)		N	X		X
Pugnose minnow (*Opsopoeodus emiliae*)		N	X		X
Suckermouth minnow (*Phenacobius mirabilis*)		N	X		X
Southern redbelly dace (*Phoxinus erythrogaster*)		N	X		
Bluntnose minnow (*Pimephales notatus*)		N	X		X
Fathead minnow (*P. promelas*)		N	X		X
Bullhead minnow (*P. vigilax*)		N	X		X
Blacknose dace (*Rhinichthys atratulus*)		N	X		
Rudd (*Scardinius erythrophthalmus*)		I	X		X
Creek chub (*Semotilus atromaculatus*)		N	X	X	X
Catostomidae					
River carpsucker (*Carpiodes carpio*)		N			X
Quillback (*C. cyprinus*)		N	X	X	X

Table 4. *Continued.*

Family Species	Protective status	Origin	Voucher status	Present in creel	Collected at BSAMA
White sucker (*Catostomus commersoni*)		N	X		X
Creek chubsucker (*Erimyzon oblongus*)		N	X		X
Lake chubsucker (*E. sucetta*)		N	X		X
Northern hog sucker (*Hypentelium nigricans*)		N	X	X	X
Smallmouth buffalo (*Ictiobus bubalus*)		N	X		X
Bigmouth buffalo (*I. cyprinellus*)		N	X		X
Black buffalo (*I. niger*)		N	X		
Spotted sucker (*Minytrema melanops*)		N	X		X
Silver redhorse (*Moxostoma anisurum*)		N	X	X	X
River redhorse (*M. carinatum*)	ILT, INSC	N	X	X	X
Black redhorse (*M. duquesnei*)		N	X	X	X
Golden redhorse (*M. erythrurum*)		N	X	X	X
Shorthead redhorse (*M. macrolepidotum*)		N	X	X	X
Ictaluridae					
Black bullhead (*Ameiurus melas*)		N	X	X	X
Yellow bullhead (*A. natalis*)		N	X	X	X
Brown bullhead (*A. nebulosus*)		N			X
Channel catfish (*Ictalurus punctatus*)		N	X	X	X
Stonecat (*Noturus flavus*)		N	X	X	X
Tadpole madtom (*N. gyrinus*)		N	X		X
Esocidae					
Grass pickerel (*Esox americanus vermiculatus*)		N	X		X
Northern pike (*E. lucius*)		N	X	X	X
Umbridae					
Central mudminnow (*Umbra limi*)		N	X		X
Salmonidae					
Rainbow trout (*Oncorhynchus mykiss*)		I			X
Aphredoderidae					
Pirate perch (*Aphredoderus sayanus*)		N	X		X
Cyprinodontidae					
Starhead topminnow (*Fundulus dispar*)		N	X		
Blackstripe topminnow (*F. notatus*)		N	X		X
Atherinidae					
Brook silverside (*Labidesthes sicculus*)		N	X		X
Inland silverside (*Menidia beryllina*)		I	X		
Gasterosteidae					
Ninespine stickleback (*Pungitius pungitius*)		N	X		
Percichthyidae					
Yellow bass (*Morone mississippiensis*)		N			X
Centrarchidae					
Rock bass (*Ambloplites rupestris*)		N	X	X	X
Green sunfish (*Lepomis cyanellus*)		N	X	X	X
Pumpkinseed (*L. gibbosus*)		N	X		X
Warmouth (*L. gulosus*)		N	X		X
Orangespotted sunfish (*L. humilis*)		N	X		X
Bluegill (*Lepomis macrochirus*)		N	X	X	X
Longear sunfish (*L. megalotis*)		N	X	X	X
Redear sunfish (*L. microlophus*)		I			X
Smallmouth bass (*Micropterus dolomieu*)		N	X	X	X
Largemouth bass (*M. salmoides*)		N	X		X
White crappie (*Pomoxis annularis*)		N	X	X	X
Black crappie (*P. nigromaculatus*)		N	X	X	X
Percidae					
Western sand darter (*Ammocrypta clara*)	ILE	N	X		
Rainbow darter (*Etheostoma caeruleum*)		N	X		X

Table 4. *Continued.*

Family Species	Protective status	Origin	Voucher status	Present in creel	Collected at BSAMA
Bluntnose darter (*E. chlorosomum*)		N	X		
Fantail darter (*E. flabellare*)		N	X		
Least darter (*E. microperca*)		N	X		X
Johnny darter (*E. nigrum*)		N	X		X
Orangethroat darter (*E. spectabile*)		N	X		
Banded darter (*E. zonale*)		N	X		X
Yellow perch (*Perca flavescens*)		N	X		X
Logperch (*Percina caprodes*)		N	X		X
Blackside darter (*P. maculata*)		N	X		X
Slenderhead darter (*P. phoxocephala*)		N	X		X
Walleye (*Stizostedion vitreum*)		N		X	X
Sciaenidae					
Freshwater drum (*Aplodinotus grunniens*)		N		X	X

significance of fish population fluctuations and the persistence and stability of assemblages in this large lowland river.

Studies of the movement of fish tagged in Braidwood Station Aquatic Monitoring Area revealed extensive movements by several fish, but also showed sedentary behavior by a portion of each population examined (Larimore and Sule 1980). The sedentary nature of smallmouth bass (*Micropterus dolomieu*) and rock bass (*Ambloplites rupestris*) was more apparent than that observed in common carp (*Cyprinus carpio*), quillback (*Carpiodes cyprinus*), shorthead redhorse (*Moxostoma macrolepidotum*), and white crappie (*Pomoxis annularis*). These findings support the early hypothesis of Funk (1955) that warmwater stream fish populations contain sedentary and mobile subpopulations.

The seven species of fish granted protective status probably remain extant in the basin, but the northern brook lamprey (*Ichthyomyzon fossor*) has not been found since 1975, nor has the blacknose shiner (*Notropis heterolepis*) since 1973 (Page et al. 1992). Collections at Braidwood Station Aquatic Monitoring Area indicated the persistence of a localized population of the pallid shiner (*Notropis amnis*), a rare minnow that was previously thought to be extirpated from Illinois (Kwak 1991). The pallid shiner was present in the catch at Braidwood Station Aquatic Monitoring Area for 9 of 13 years (Peterson 1991). The river redhorse (*Moxostoma carinatum*) is locally abundant in the Kankakee River, but has a limited regional distribution. It has been collected in Braidwood Station Aquatic Monitoring Area each year in considerable numbers and was present in all three surveys represented in Fig. 3a (Page et al. 1979; Robertson and Ledet 1981; Sallee et al. 1987; Peterson 1991). Ironically, the river redhorse was also the fourth most important fish (by weight) in the sport-fishing harvest during 1978 and 1979, before it was listed as a protected species (Graham et al. 1984). The other protected species are rare in the Kankakee River and are known to occur at only one or two locations in the basin (Page et al. 1992).

The quality of the sport fishery of the Kankakee River was investigated in a 2-year creel survey conducted on a 40-km reach of the lower river during 1978 and 1979 (Graham et al. 1984). The fishing effort on the lower Kankakee River (3,823 angler-h/km/year) was several times larger than those reported in comparable surveys reviewed by Graham et al. (1984), but the catch rate (0.12 fish/h) was somewhat low. The river is popular because of its scenic value and proximity to the Chicago metropolitan area. Many anglers only casually seek fish and engage in other outdoor activities to enjoy the total outdoor experience. Most fishing is done from shore in pursuit of no particular species, but channel catfish (*Ictalurus punctatus*), smallmouth bass, and walleye (*Stizostedion vitreum*) were the most sought-after fishes. Twenty-five species were found in the possession of anglers (Table 4), but common carp, channel catfish, and shorthead redhorse dominated the harvest, composing over 68% of the biomass observed. Commercial fishing is prohibited on the Kankakee River.

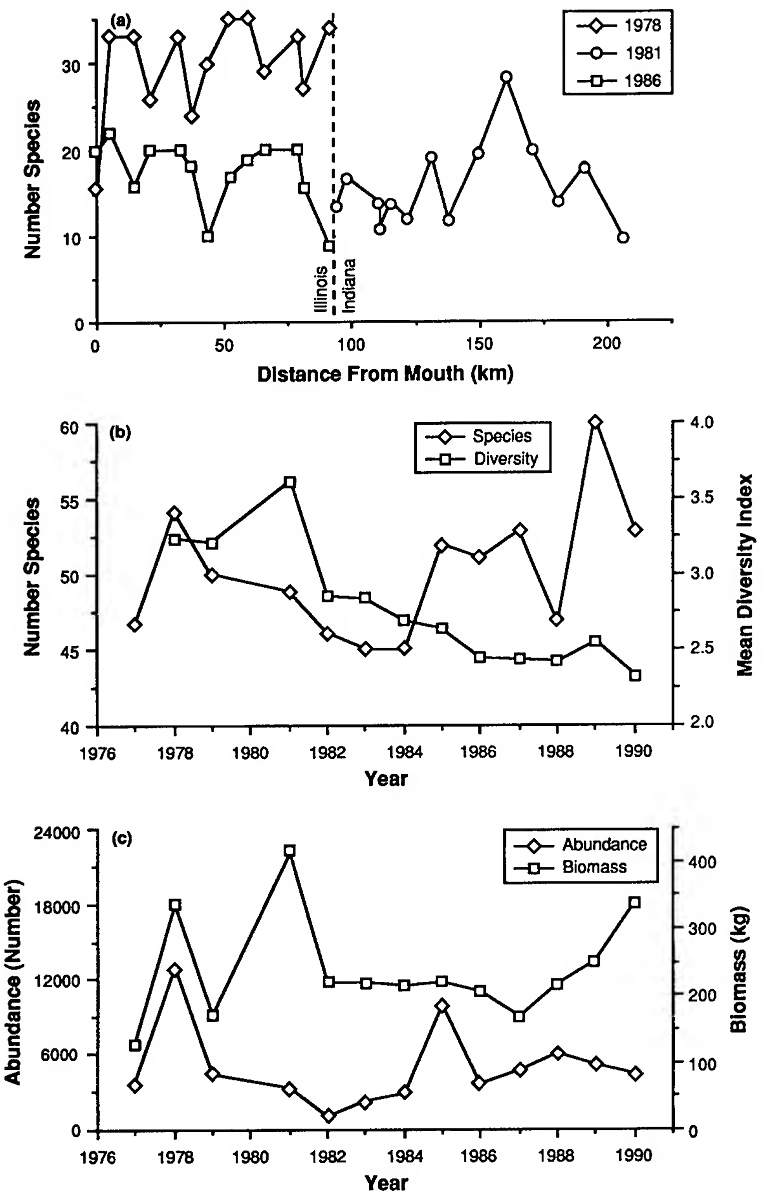

Fig. 3. Longitudinal and temporal trends in fishes of the Kankakee River: (a) longitudinal distribution of species collected in three recent surveys, vertical broken line denotes the Illinois-Indiana state line; (b) number of species and mean diversity index according to year in August surveys of Braidwood Station Aquatic Monitoring Area (BSAMA); and (c) total abundance and biomass according to year in August surveys of the BSAMA. Data are from Page et al. (1979), Robertson and Ledet (1981), Sallee et al. (1987), Peterson (1991), and 12 previous annual reports.

Factors Influencing the Distribution and Abundance of Fauna

Human activity has profoundly impacted flowing waters in all parts of the world, to such an extent that it would be nearly impossible to find an unaffected stream (Hynes 1970). Without a doubt, drainage of lowlands and channelization of the Kankakee River channel and tributaries have had the single greatest effect of all human actions on the river. These activities, in combination with other anthropogenic and natural factors, create the environment that dictates the occurrence of aquatic life in the stream.

Channel Modifications and Drainage

Channel modifications, and drainage of lowlands and the marginal floodplain, directly impact aquatic fauna through destruction or degradation of habitat or by limiting its availability. Channelization also results in loss of stream length. Over

400 km of the meandering Kankakee River in Indiana has been converted to a straight, deep channel 132 km long (Ivens et al. 1981). Straightening the river channel in Indiana isolated many natural river meanders, led to the draining of bottomland sloughs, marshes, and lakes, and contributed to increased erosion and flooding downstream. Wilson and Clark (1912) noted that "dredging entirely annihilates the mussel fauna" in impacted areas of the Kankakee River basin. Dredging of tributaries and tiling of agricultural lands were also integral parts of the drainage process. Such modifications to the physical environment reduce microhabitat diversity—a variable that has been linked to the occurrence and diversity in benthic macroinvertebrates and fishes of the Kankakee River (Larimore and Sule 1980; Brigham et al. 1981).

These alterations have had the most dramatic effect on lacustrine species and are responsible for the reduced range of 13 species of fish in Illinois (Smith 1971). Undesirable shifts in species composition and the decline in commercial and sport fish catches were directly attributable to habitat loss and sedimentation following the construction of levees and drainage of bottomlands of the Illinois River (Sparks and Starrett 1975). Twenty-five fish species have been associated with the floodplain of the Kankakee River near the Momence Wetlands (Kwak 1988). A high proportion of juveniles (55%) and the tendency of juveniles of some species to remain in isolated backwaters demonstrated the value of the Kankakee River floodplain as spawning and nursery habitats. Floodplain habitat is probably critical to the survival of the pallid shiner (Kwak 1991), blacknose shiner (Smith 1971), and weed shiner (*Notropis texanus*; Ross and Baker 1983), three rare and protected fishes of the Kankakee River.

A survey of fishes in the Indiana portion of the Kankakee River basin found that 9 of the 48 species collected occurred only in backwater habitat (Robertson and Ledet 1981). This survey also indicated the importance of instream cover (woody debris and root systems) as fish habitat. Fish diversity, density, and biomass were all greater in areas containing cover compared with areas lacking cover.

Neither of the low-head dams on the Kankakee River exceeds 4 m in height (Barker et al. 1967), and during high water the damming effect on the river is minimal (Ivens et al. 1981). These dams are probably not passable by fish during high water, and they have formed a barrier to fish movements and have altered nearby habitat since their construction. Channelization, drainage, and dams exert direct effects on aquatic life through habitat loss and can also induce changes in other environmental variables such as sedimentation, flow rates, temperature, and water quality; these are discussed below.

Sedimentation

The effects of sedimentation include loss of water clarity with subsequent disappearance of aquatic vegetation, and deposition of silt over coarser substrates of bedrock, cobble, gravel, or sand (Smith 1971). Substrate composition is the chief factor that determines the distribution and abundance of benthic macroinvertebrates in the Kankakee River (Larimore and Sule 1980; Brigham et al. 1981). Sites with more complex substrates support more benthic macroinvertebrate taxa, and Brigham et al. (1981) estimated that 36% to 65% of these taxa would be eliminated from areas of the river if sediment deposition increased.

Substrate is also an important factor influencing the occurrence of mussels in the Kankakee River. Fine-particle substrates (sand or silt-sand mixtures) support few, if any, mussels in the Kankakee River (Brigham et al. 1981; Suloway 1981). The rate of decline in mussel populations has been greater in the upstream sandy areas of the river and may be caused by sedimentation (Suloway 1981). Two large dense mussel beds in Illinois near Momence and Aroma Park represent a significant portion of the mussel fauna of the river and may be particularly vulnerable to siltation.

Excessive siltation was implicated as the principal cause of decline and extirpation of native Illinois fishes (Smith 1971). Many species of fish rely on coarse substrates for feeding and spawning. The severe reduction in range of the state-endangered weed shiner has been attributed to the loss of gravel and sand substrates to silt (Smith 1971). Areas of the Kankakee River where sand and silt-sand substrates predominate support fewer species, lower densities, and less biomass of fish than do areas with coarse substrates (Brigham et al. 1981). Nine species of fish found in the river are dependent on rock substrates for survival, and Brigham et al. (1981) projected a 30% decrease in the number of species and associated decreases in density and biomass if coarse substrates were filled in by sedimentation.

Flow and Water Temperature

Flow regime and water temperature have been implicated as major influences on the dynamics and density of warmwater stream fish assemblages (Ross et al. 1985; Matthews et al. 1988; Schlosser and Ebel 1989). Furthermore, Smith (1971) listed water temperature and desiccation during drought as two factors responsible for the decimation of Illinois stream fishes. In recent decades, the water table driving Illinois streams has fluctuated more widely than it did before 1930, and when streams cease flowing, the effect on aquatic life can be devastating, especially to headwater species (Smith 1971).

The flood pulse concept, recently developed by Junk et al. (1989), described in general terms the driving forces of flow and temperature that have been shown by others to affect the dynamics of the biota in the Kankakee River (Kwak and Larimore 1987; Kwak 1991; Sallee et al. 1991). In large natural floodplain rivers, the flood pulse is a predictable event of long duration, but in headwater streams or in heavily modified rivers with floodplains that have been leveed or drained, such as the Kankakee River, the flood pulse is highly unpredictable and relatively brief (Welcomme 1979; Junk et al. 1989). Thus, organisms in low-order stream environments are limited in adaptation and availability from utilizing the floodplain (Junk et al. 1989), and distinct fish assemblages have been described for the river channel and fringing floodplain environments (Ross and Baker 1983).

Fish yields and production are strongly related to the extent of accessible floodplain, whereas the river channel may serve as a migration route for most fishes (Junk et al. 1989). The Kankakee River has distinct fish assemblages associated with the floodplain, and when these flood-exploitative fishes are forced off the floodplain, they continue to seek favorable backwater habitat (Kwak 1988). The degree of fish movement between the Kankakee River channel and floodplain is positively related to flow, and a critical discharge volume, below which fish are denied access to the floodplain, was estimated as 44.5 m^3/s for the Momence Wetlands area of the river (Kwak 1988). That discharge is less than the average for that area (54.7 m^3/s) but is only exceeded about 45% of the year (Bhowmik et al. 1980).

In temperate regions, temperature can modify the effects of the flood pulse (Junk et al. 1989). Variations of flow and temperature have been examined as potential factors influencing Kankakee River fish populations, and several models have been developed to describe environmental influences on fishes. An analysis of factors affecting the total catch of all fishes and catch of four species (bluntnose minnow, *Pimephales notatus*; golden redhorse, *Moxostoma erythrurum*; smallmouth bass; and rock bass) was performed on the first 9 years (1977–86, excluding 1980) of August surveys of Braidwood Station Aquatic Monitoring Area (Kwak and Larimore 1987). Total fish abundance was positively related to spring (May–June) temperature but negatively related to spring flow in the river. Environmental conditions (flow) during sampling explained most of the variation in fish biomass. Catch (by number or biomass) and young-of-the-year recruitment for each species examined was related to at least one measure of river discharge or temperature during spring or summer.

Sallee et al. (1991) examined discharge and discharge fluctuations in the Kankakee River during spring, the spawning period, and winter as potential influences on smallmouth bass catch during July surveys of 13 sites. They found catch rates of age-1, -2, and -3 smallmouth bass to be inversely related to variability in discharge during the preceding winter. Measures of flow and temperature were also explored as influences on pallid shiners at Braidwood Station Aquatic Monitoring Area (Kwak 1991). The catch of juvenile pallid shiners was positively correlated with minimum flows in May and June and negatively correlated with March temperature. The total pallid shiner catch was positively related to March peak flow. Conditions during sampling did not seem to influence the catch rate of pallid shiners. Optimal conditions for spring spawners, such as the pallid shiner, are likely to occur when flooding and temperature rises are coupled, as suggested by Junk et al. (1989). Such conditions are less likely to occur in modified systems such as the Kankakee River, where flooding is usually intense and of short duration.

In the Illinois portion of the Kankakee River basin, only the Kankakee metropolitan area and Wilmington obtain surface water from the Kankakee River. The city of Joliet, Illinois, has recently proposed a plan to withdraw water from the Kankakee River because of contaminants in that city's current water supply (R. D. Sallee, Illinois Department of Conservation, personal communication). A study of water use in the Kankakee area revealed that the volume of water withdrawn from the river increases during dry periods (LaTour 1991), also a critical period to the aquatic biota of the river. An instream-flow needs analysis, per-

formed by Herricks et al. (1983), may be useful in determining critical minimum flows for aquatic life in the river. The protection of minimum flows in the Kankakee River is likely to become a volatile and formidable, but crucial, task for resource managers.

Water Quality

Water pollution includes industrial, domestic, and agricultural pollutants, as well as siltation, all of which occur in the Kankakee River. Smith (1971) cited pollution as the cause for extirpation or decimation of seven Illinois fishes, including the greater redhorse (*Moxostoma valenciennesi*). The greater redhorse once occurred in the upper reaches of the Des Plaines River, but was believed to be extirpated from Illinois sometime after 1901, when that system became polluted. Recently, a relict population was discovered downstream in the Illinois River (Seegert 1986). This finding leaves open the possibility of a similar occurrence in the Kankakee River.

Sporadic fish kills occur in Illinois streams, including the Kankakee River, and are usually a result of episodic discharges of toxicants or organic waste (Smith 1971; Northern Illinois Anglers Association 1988). As recently as 1988, an investigation revealed repeated water quality violations by the Kankakee metropolitan wastewater treatment facility, primarily exceeding limits of biological oxygen demand and suspended solids (Northern Illinois Anglers Association 1988). The report implicated effluent from that facility in causing a fish kill that impacted 11 km of stream and destroyed numerous fish, mussels, and crustaceans by lowering dissolved oxygen and increasing ammonia concentrations. Such episodic events may have serious consequences in the Kankakee River, given the number of rare species and relict populations that occur there.

Harvest

The sport fishing harvest may influence abundance and alter assemblages of fishes in the Kankakee River, but is probably not detrimental to the health of the ecosystem. Surveys indicate the presence of abundant and rich assemblages of fishes in the river, but a low harvest rate (Page et al. 1979; Graham et al. 1984; Peterson 1991). Select species, however, may be affected to a greater degree by harvest. Larimore and Sule (1980) estimated an annual mortality rate of 61% for smallmouth bass in Braidwood Station Aquatic Monitoring Area. This mortality rate is high compared with those reported for other smallmouth bass populations (Coble 1975) and indicates that harvest may exert substantial influence on the population dynamics of this species. Although the river redhorse is protected at the state level (Table 4), past sport harvest (Graham et al. 1984) and an incidental catch that presumably continues may affect that species.

Past overharvest may have contributed to the declines in the mussel fauna of the Kankakee River (Suloway 1981). Shells were harvested from the early to mid 1900's for the pearl button industry and more recently for sale to the cultured pearl industry of Japan; however, mussel harvest on the Kankakee River is currently prohibited.

Management Recommendations

The following measures are recommended for protection and enhancement of this unique river resource and are discussed below: (1) restrict and minimize channelization, clearing, and construction on the river, floodplain, and feeder streams; (2) protect remaining riparian habitat from development, especially forested floodplain and wetlands; (3) modify land-use practices, primarily agricultural, to reduce levels of siltation and pollution; (4) determine and protect critical minimum flows within the basin; (5) apply and evaluate river restoration techniques to stabilize banks and restore portions of the river channel to a natural flow pattern; and (6) integrate protection and enhancement into a holistic, basinwide management plan.

Channelization, clearing, and construction on the river, floodplain, and feeder streams must be restricted and minimized. Additional dredging, clearing, or construction will lead to increased erosion, sedimentation, and habitat degradation, which will be detrimental to aquatic life. Efforts to further constrict the floodplain, as has been proposed in Indiana through a system of levees (SEG Engineers and Consultants, Inc. 1989), are destructive to the river ecosystem for the economic gain of a few individuals. Furthermore, additional restriction of the river will result in economic losses downstream, where the severity of flooding will certainly increase with higher and sharper peak flows and shortened flood duration (Grover and Harrington 1966). In such circumstances of conflicting goals, an optimal course to follow may be one of implement-

ing no action, to preserve existing conditions as a minimum management goal.

Riparian habitat, especially forested floodplain and wetlands, must be rigorously protected from development. The diverse fauna found in the Kankakee River is a result of the corresponding diversity in habitat. The moving littoral zone that is created when fringing floodplains are inundated allows rapid recycling of organic materials and nutrients, resulting in high production at all trophic levels (Junk et al. 1989). Besides the direct effects on aquatic life, streamside wetlands provide flood control, drought prevention, water quality enhancement, and sedimentation control (Mitsch et al. 1979; Bell 1981). Such functions have substantial economic value, which has been quantified for riparian zones on the Kankakee River (Mitsch et al. 1979).

Land-use practices, primarily agricultural, should be modified to reduce levels of siltation and pollution. As of 1967, 75% of the land in the Illinois portion of the Kankakee River basin was in grain farms (Barker et al. 1967). It is preferable to control sediment, fertilizer, and pesticides on the watershed, before these substances reach the river. Conservative management practices on the watershed should be implemented, including low-till cultivation, contour farming, border and buffer strips, and other related conservation measures designed to reduce erosion and pollution.

Critical minimum flows within the basin must be determined and protected. Because flooding on the Kankakee River has received so much attention in the past, the negative consequences that low flow rates can exert on aquatic life have been largely overlooked. A variety of methods are currently available to determine instream flow needs (Morhardt 1986). The proximity of the Kankakee River to major metropolitan, industrial, and agricultural areas, and the increasing demand on its limited surface waters, qualify the basin for detailed instream flow assessment followed by protection of critical minimum flows.

River restoration techniques to stabilize banks and restore portions of the river channel to a natural flow pattern (Gore 1985; Boon et al. 1992) should be applied and evaluated. Exposed stream banks of the main channel of the river and feeder streams and ditches should be stabilized by natural methods if possible (e.g., seeding or plantings) or artificial means if necessary (e.g., grading and rip-rap, followed by soil and seed). Some wetlands are worth more for flood control than for agriculture and never should have been drained (Bell 1981). The Kankakee River channel in Indiana has not sought a return to its historical flow pattern, but numerous oxbows that were once the natural meanders of the river remain on the floodplain (Fig. 2). It is beyond the scope of this report to present a specific proposal to restore the flow of river segments to historical patterns or a modified natural flow, but such efforts would result in a variety of ecological and economic long-term benefits. Remedial measures designed to control sedimentation, such as construction of settling basins or sediment removal by dredging, are temporary solutions requiring ongoing maintenance and should be avoided.

Protection and enhancement should be integrated into a holistic, basinwide management plan. Although a profound demarcation in habitat, fauna, and human values occurs in the Kankakee River at the state line, a river basin, like any ecosystem, is a single unit. The river's past is compelling evidence that it cannot be managed effectively as two artificially designated subunits with conflicting strategies and goals. Regardless of this legacy, the Kankakee River has retained a wealth of culture and natural resources, and further degradation of the ecosystem is unacceptable. Conservation departments of Illinois and Indiana, along with 27 other states, have recently signed the Mississippi Interstate Cooperative Resource Agreement. These states have agreed to share resources, facilities, and funding for the preparation and implementation of long-range strategic plans and thus agree to the mandate "to assess the Mississippi River drainage fishery resources and habitat requirements to protect, maintain, and enhance interstate fish species in the basin." The information presented in this study and the objectives and goals of the Mississippi Interstate Cooperative Resource Agreement may now serve as a foundation upon which to design and implement an ecologically sound management plan for the Kankakee River. The common goals of all stewards of the Kankakee River must include protection, enhancement, and wise use of this unique resource.

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The Wabash River: Progress and Promise

by

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Abstract. The Wabash River originates in the agricultural drains and ditches of northwestern Ohio and is most influenced by agriculture, coal strip-mining, industry, and municipalities. The fish community improved sharply recently with increased densities of most species populations, except for common carp and gizzard shad. Increased predator pressure reduced the latter to fewer, larger individuals. Some populations expanded into previously unoccupied areas of the river. The average size of many species increased, raising questions of greater longevity or faster growth. This improvement probably resulted from a combination of long-term 50% reduction in biochemical oxygen demand loading through improved point source waste treatment, a low-flow summer in 1983 that facilitated good reproduction and survival through the first year, and a 25% reduction in agricultural loadings to the river during the 1983 Payment In Kind (PIK) program, which reduced row-crop acreage to 75% of normal. Continued improvement may depend on limiting nutrient delivery and reducing diatom densities. Modeling studies indicate that phytoplankton respiration is responsible for 50–70% of the dissolved oxygen deficit. During the summer, diatom densities may exceed 100,000/mL and chlorophyll *a* more than 200 µg/L in parts of the mainstem where fish kills have been recorded.

Historical Studies and Events

The Wabash River and its largest tributary, the White River, figure prominently in the early development of knowledge about running water biota. Charles Alexander Lesueur, a member of the "Boatload of Knowledge" from Pittsburgh, arrived in New Harmony on the lower Wabash River in January 1826. He was a naturalist who first described species of fish from lakes Erie and Ontario and who devoted the next 10 years to traveling up and down the Mississippi River system sketching extensively and writing sporadically. It was at New Harmony where he published in 1827 "American Ichthyology Or, Natural History of the Fishes of North America: with Coloured Figures from Drawings executed in Nature" (Gerking 1957).

Lesueur was a poor writer, and he failed to develop this work at New Harmony as he had intended. His excellent sketches, however, provide an unusual portrait of the riverside lifestyle of those times (Bonnemains 1984). Most of his limited writings and extensive sketches returned with him to France a decade after his arrival.

Thomas Say, another "Boatload" passenger, devoted his life to the study of insects and mollusks of the area and completed several publications before his death and burial at New Harmony. Constantine Samuel Rafinesque was an occasional visitor who had preceded Lesueur down the Ohio River in 1818 and began an active ichthyological career at Transylvania College in Kentucky (Rafinesque 1820).

The study of fishes expanded greatly when David Starr Jordan arrived in Indianapolis in 1874. He had previously studied fish with Louis Agassiz at his summer school on Penikese Island off the coast of Massachusetts. While teaching first in high school and then at Butler University, Jordan and Herbert E. Copeland, a colleague from Cornell University, avidly collected fish from the nearby White River and studied the life history of resident darters. They also collected fish at the falls of the Ohio River near Jeffersonville, Indiana, attempting to clarify the hasty work of Rafinesque, and they

began a catalogue of the freshwater fishes of the United States. Jordan's first paper (1875) described the various species he had personally examined from the White, Wabash, and Ohio rivers.

Jordan soon explored streams in neighboring states, often traveling on foot and in the company of Charles Gilbert, A. W. Brayton, and B. W. Evermann. By 1890 he had visited every state in the Union. In 1879, Jordan joined Indiana University, which soon became a center of ichthyologic research, producing such graduates as Joseph Swain, Oliver P. Jenkins, Amos Butler, Albert B. Ulrey, Stephen A. Forbes, Oliver P. Hay, and Carl H. Eigenmann. The first comprehensive works on North American fishes were completed here (Jordan and Gilbert 1883; Jordan and Evermann 1896–1900; Jordan and Evermann 1934). Jordan and his students continued collecting fish from the Wabash and White rivers and their tributaries (Jenkins 1887; Evermann and Jenkins 1892) until 1891, when he assumed the presidency of Stanford University.

He found the "fish fauna of the Lower Wabash . . . to be unexpectedly rich . . .," especially in the abundance and number of species of darters. "The upper Wabash and most of its tributaries are clear streams . . .,"but "Towards its junction with the Ohio R. the Wabash becomes a large river with moderate current, the water not very clear, and the bottom covered with gravel and sand in which grow many water plants. The tributary streams are mostly sluggish and yellow with clay and mud" (Jordan 1890).

By Jordan's time the native fish populations were already extensively altered. Land had been cleared for agricultural fields, and dams were built for grist mills. During the period 1825–55, Indiana busily constructed canals in an effort to provide better commercial links with the eastern states. The Wabash and Erie Canal started at Fort Wayne and paralleled the Wabash River south to Terre Haute. From there it proceeded southeast to the Eel River, a tributary of the White River, where it was to join the Central Canal at Indianapolis. That linkage was never completed, but the Wabash and Erie Canal crept southward to the White River and ultimately linked up with the Pigeon Creek Canal and the Ohio River at Evansville, Indiana.

The damage to rivers and streams during this period can only be inferred, but it must have been considerable. Elevated, waterproof aqueducts had to be constructed at each tributary. Feeder canals channeled water into the Wabash and Erie Canal from tributaries and wetlands, draining the latter and creating additional farmlands for a growing population. Dams and reservoirs were created to ensure adequate water during dry summers. The condition of Indiana's streams was summarized by Jordan in an address to the Fish and Game Convention in 1899: ". . . that there never were such [smallmouth] bass streams as in Indiana, and that White River is the best bass stream they have ever known. I think probably nothing better could be done--if we could devise a way—than to bring the bass back, and where there are now a dozen scattering fish put two or three thousand." Thus the seeds were sown for an extensive stocking program, and there was much excitement about a great new species—carp—which would put fish back into Indiana lakes and streams.

Jordan was too late to document the natural fish communities of the Wabash and White rivers. He was in time, however, to witness the first side effects of industrial development, which subsequently imposed an additional heavy burden on those rivers.

A 40-year gap followed Jordan's departure before Gerking (1945) undertook comprehensive collections of fish at 412 scattered sites from 1940 to 1943. Echoing Jordan's remarks, Gerking found that "Streams in the northern third of the state often run clear. . . . Creeks of the central and southern part of Indiana are usually turbid and warm. Many of the southwestern streams are slow-moving and usually carry a heavy load of suspended material."

Most of Gerking's collections were made with quarter-inch-mesh seines in shallow, accessible sites, although gill nets and commercial catches from large rivers and lakes were sometimes used. He was able to assess changes in the smaller species because these same methods were employed by earlier collectors. Good records of fish distribution and abundance in larger rivers were not available until the development of electrofishing collecting methods during the 1950's. The primary focus of the following discussion is the mainstem of the Wabash River.

Physical Attributes of the Wabash River

The Wabash River originates in the agricultural drains and ditches in northwestern Ohio near Fort Recovery at an altitude of about 267 m

and flows southwesterly 764 km to enter the Ohio River at an altitude of about 97 m near Mount Carmel, Illinois (Fig. 1). It flows freely throughout its length except for Huntington Reservoir at river kilometer (rkm) 662. Its average rate of descent is about 0.22 m/km, but the river is best divided into two sections: a relatively steep upper section with a rate of fall of 0.454 m/km and the longer, lower section with a rate of fall of only 0.123 m/km. The transition between these dissimilar segments is abrupt and occurs at about rkm 570 near Logansport, Indiana.

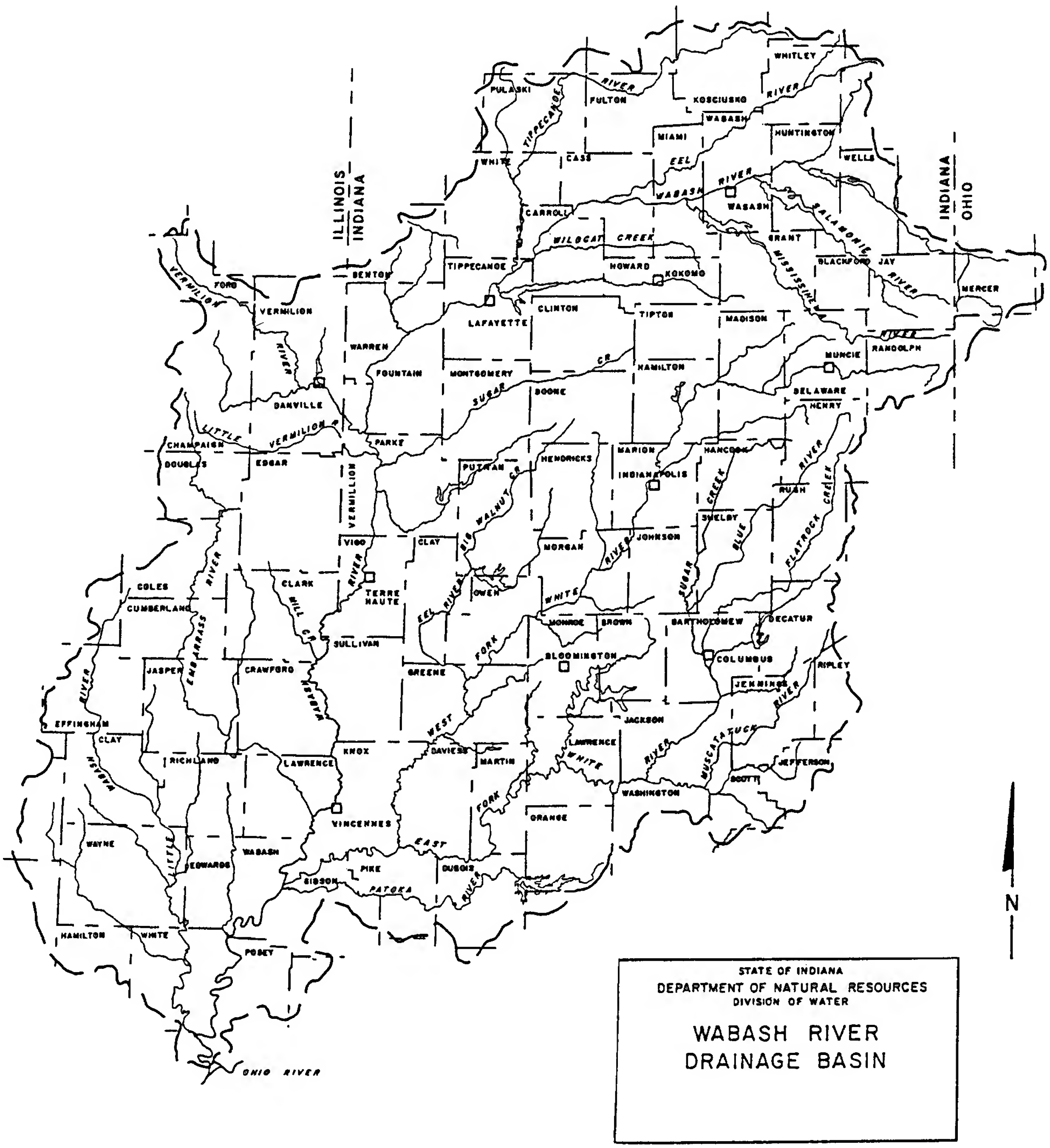

Fig. 1. Principal rivers and streams of the Wabash River drainage basin.

The Wabash River basin is the largest Ohio River tributary basin, except for the Tennessee River basin, with a total land area of 85,500 km^2. It receives water from 62,000 km^2 of Indiana, 22,540 km^2 of Illinois, and 740 km^2 of Ohio. The Wabash River drains 65.6% of Indiana's area (Clark 1980). Except for Lake Michigan, it is the largest body of water in Indiana, with more than 100 km^2 of surface area.

About two-thirds of the watershed is in agricultural cropland, the highest proportion within the Ohio River basin (ORSANCO 1990a). An additional 8.2% is in pasture or grassland. Forests or woodland constitute only 13.5% of the basin's land area, the second smallest proportion within the Ohio River basin. Agricultural development is considerably greater in the upper half of the basin. The lower half of the basin has a greater percentage of forests, as well as most of the surface coal mines. The upper half of the Wabash River lies in the Eastern Corn Belt Plains ecoregion, while the lower half is contained within the Interior River Lowland ecoregion (Omernik and Gallant 1988).

During the Pleistocene Epoch, glaciers moved into Indiana at least three times, with the Illinois boundary extending nearly to the mouth of the Wabash River. This resulted in deposits of glacial drift from less than 15 m thick in the south to more than 90 m in the north. Extensive till deposits cover the northern basin, with sand and gravel outwash deposits occurring along major rivers and streams. The middle Wabash River flows through an extensive deposit of loess. The major bedrock consists of Pennsylvanian and Mississippian rocks.

Homoya et al. (1986) delineated 12 natural regions of Indiana, 11 of which are based importantly on the dominant natural vegetation composition. Their Central Till Plain natural region, which roughly corresponds with the Eastern Corn Belt Plains ecoregion, is subdivided into three Sections: Bluffton Till Plain, Tipton Till Plain, and Entrenched Valley. The Wabash River flows within the Bluffton Till Plain from its origination at rkm 764 to rkm 570 near Logansport, Indiana. From there to rkm 370 near Clinton, Indiana, it is contained within the Entrenched Valley, and for the remainder of its journey it flows through the Southern Bottomlands natural region.

Homoya et al. (1986) also distinguished a separate Big Rivers natural region that includes the lower Wabash River from about rkm 467 near Attica to its mouth and the White River from its mouth to the confluence of the East and West forks.

In terms of average discharge, the Wabash River is about one-fourth the size of the Ohio River where the two rivers meet. On the average nearly 850 m^3/s is discharged into the Ohio River (Todd 1970), making the Wabash River the 12th largest river in the United States. The White River (drainage basin area = 29,394 km^2), a major tributary, is 69.1% as large as the Wabash River basin (42,538 km^2) where they join at rkm 154. In terms of discharge, however, the two rivers produce nearly the same average volume of water, 335.6 m^3/s for the White River and 341.5 m^3/s for the Wabash River (Arvin 1989). Seasonal variations in discharge are pronounced, with the highest discharge in March or April averaging nearly four times larger than that of August, September, and October.

Although Huntington Reservoir is the only mainstem reservoir, river discharge is influenced somewhat by several other flood control reservoirs on tributaries. Salamonie, Mississinnewa, and Mansfield reservoirs affect the Wabash River flow; Cagles Mill and Monroe reservoirs affect discharge in the White River.

Temperature

Normal water temperatures are usually at or close to 0° C during winter months, but rise steadily from March through June. Temperatures often exceed 25° C during the low-flow months of July, August, and early September, and sometimes they exceed 32° C. Temperatures decline precipitously in fall.

There are many reports on research conducted on the Wabash and White rivers regarding the effects of electric generating stations on fish populations and other parts of the aquatic community. Mainstem stations located near Cayuga, Terre Haute, and Fairbanks divert river water for purposes of cooling steam after it has passed through the turbine generators. Space does not permit a discussion of ecological effects here.

Suspended Solids Concentration

Wabash River water is usually turbid and aesthetically displeasing. It detracts from the recreational potential of rivers and streams because few people care to swim, canoe, or fish in water perceived as dirty. Turbid water is also ecologically damaging because it severely limits food location

by sport fishes, most of which locate food items visually. Furthermore, deposition of suspended sediment interferes with reproduction of many species.

Suspended solids concentration (SSC) is generally high, averaging 60–70 mg/L in the upper Wabash River and exceeding 150 mg/L in the lower river. High concentrations of algae (>100,000/mL) contribute to elevated summer turbidities, at which time the Secchi depth ranges from 20 to 40 cm. The SSC increases twofold from the upper river at Peru to the middle river at Vincennes (Table 1) and even more by the time it reaches the Ohio River. Crawford and Mansue (1988) found a statistically ($P < 0.05$) significant increase in discharge at Lafayette during the period 1964–82, but no change in SSC, flow-adjusted SSC, or total suspended-sediment (SS) discharged. The median SSC was 66 mg/L (mean = 87 mg/L; range = 6–980 mg/L). The median SS discharge was 714 tons/day (range = 13–81,500 tons/day). They mathematically described the relation between water discharge and SS discharge at Lafayette for the period 1951–80 and the particle size, 68% of which was clay.

HydroQual, Inc. (1984) used Indiana State Board of Health data from 1968 to 1981 to describe SSC and SS loads as a function of summer discharge. The equations are SSC(mg/L) = $5{,}800 \times (1.00132^{Q}/Q)$ for flows less than 2,500 cfs; SSC(mg/L) = $5{,}600 \times (1.000303^{Q}/Q)$ for flows of 2,500–6,300 cfs; and SSC(mg/L) = $131{,}000 \times (1.000185^{Q}/Q)$ for flows greater than 6,300 cfs. Downriver from its junction with White River, the median SSC was 116 mg/L (mean = 150 mg/L) and the median SS discharge was 5.66×10^{6} kg/day (6,240 tons/day) for the Wabash River at New Harmony, Indiana, from 1975 through 1984 (ORSANCO 1990b).

Chemical Attributes of the Wabash River

Major biotic modifications have occurred in the past decade, changes that may be correlated with long-term changes in the physicochemical environment. The character of the fish communities changes substantially over the river's length, and these differences might also be associated with spatial variations in the physical and chemical environment. The average concentrations of some chemical constituents during recent years at several locations is shown in Table 1.

Using the Seasonal Kendall Test, ORSANCO (1990b) analyzed trends in data from 1977 to 1987 at 33 stations within the Ohio River basin, including the Wabash River at New Harmony, Indiana. A statistically significant decrease in copper was noted, but no statistical change occurred for total suspended solids, total dissolved solids, hardness, sulfate, phenolics, iron, lead, mercury, or zinc.

Martin and Crawford (1987) found that sulfate and suspended solids concentrations increased downriver, but no spatial differences were noted for specific conductance, pH, or total alkalinity. The specific conductance was lower during summer (507–528 μS-cm) than at other seasons (annual average 550–560 μS-cm), but there were no annual or summer spatial differences. Total alkalinity was slightly lower during summer (annual alkalinity = 190–200 mg/L; summer alkalinity = 180–190 mg/L) with no noticeable spatial differences.

Ammonia averages near 0.2 mg/L in the upper river to about 0.15 mg/L in the lower river. Combined nitrite and nitrate concentrations average between 3.0 and 3.5 mg/L throughout most of the river. Organic nitrogen averages about 1.0 mg/L and seems to have decreased from 1977 to 1987.

Phosphate concentration has averaged about 0.2 mg/L since 1971, when phosphate detergents were first banned in Indiana. The exact magnitude of the decrease is difficult to assess, however, because of changes in the analytic procedure by the Indiana State Board of Health. Concentrations increase slightly downriver.

Of all the chemical constituents examined, biochemical oxygen demand (BOD) has changed most over time, averaging 4.5–5.0 mg/L throughout the river during the 1960's, but then declining to 2.5–3.0 mg/L at present. Improved waste treatment by industries and municipalities during the past 2 decades is believed to be responsible for the decrease.

An examination of annual changes in BOD at Lafayette, however, reveals that BOD is lower only from October through June (Fig. 2). During July, August, and September, BOD levels are as high as in the past (4.0–6.0 mg/L), probably the result of high concentrations of phytoplankton. HydroQual, Inc. (1984) estimated that nonpoint sources such as agriculture contribute 60–80% of carbonaceous BOD during summer and that phytoplankton respiration accounted for 50–70% of the dissolved oxygen deficit in the middle river.

Table 1. Mean concentration and range of some physicochemical water quality parameters for the period 1977–87.[a]

Parameter	Huntington (rkm 658)	Peru (rkm 595)	Lafayette (rkm 502)	Montezuma (rkm 386)	Terre Haute (rkm 351)	Vincennes (rkm 209)	New Harmony[b] (rkm 83)
Total suspended solids (mg/L)	64.9 (5–1,000)	66.2 (3–1,260)	77.0 (3–1,300)	113.7 (4–2,430)	116.7 (7–2,110)	112.8 (6–980)	157.2
Conductivity (µS/cm)	597.6 (200–1,160)	562.3 (280–1,600)	533.4 (230–870)	595.7 (341–920)	562.2 (226–900)	552.0 (240–880)	488.7
Alkalinity[c] (mg/L as $CaCO_3$)	173.0 (90–275)	177.4 (116–258)	197.2 (117–270)	198.4 (122–276)	192.8 (90–260)	187.8 (112–252)	
Phosphate (mg/L)	0.217 (0.06–1.4)	0.182 (0.05–1.0)	0.170 (0.03–0.74)	0.202 (0.06–1.30)	0.207 (0.05–1.40)	0.204 (0.05–0.51)	0.300
Sulfate[d] (mg/L)	89.1 (21–230)	64.1 (21–100)	63.1 (28–90)	66.9 (30–90)	68.1 (31–100)	69.1 (28–120)	60.1
Ammonia (mg/L)	0.260 (0.1–0.2)	0.195 (0.1–1.8)	0.166 (0.1–1.3)	0.153 (0.1–1.0)	0.145 (0.1–1.8)	0.157 (0.1–1.0)	0.145
Nitrate (mg/L)	4.09 (0.1–15.0)	3.50 (0.5–8.9)	3.29 (0.2–10.1)	3.67 (0.1–10.6)	3.43 (0.1–9.0)	3.19 (0.1–7.4)	2.17
Organic nitrogen (mg/L)	0.996	0.993	0.900	1.183			
pH	7.65	7.72	7.80	7.81	7.77	7.86	

[a] Except where noted, data from Indiana Department of Environmental Management, Office of Water Management, Monitoring Station Records—Rivers and Streams. Published annually.
[b] ORSANCO 1990b.
[c] 1986–90 only.
[d] 1977–85 only.

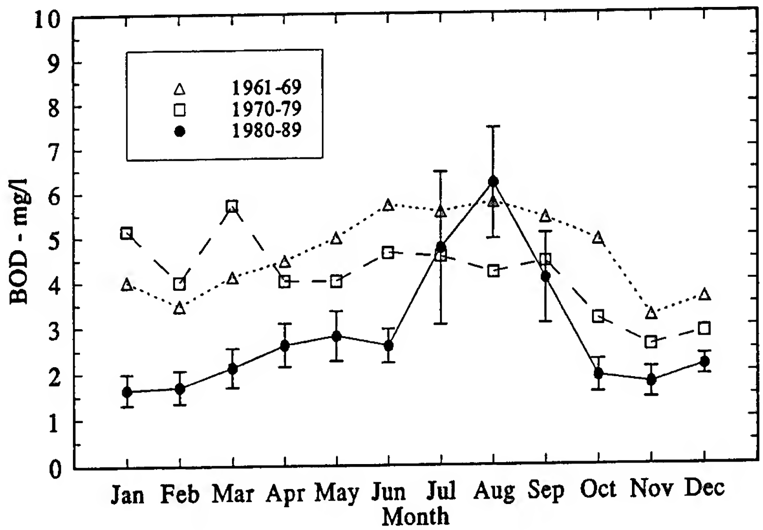

Fig. 2. Annual pattern of biochemical oxygen demand in the Wabash River at Lafayette, Indiana, during the 1960's, 1970's, and 1980's.

Table 2. Mean concentration (μg/L) of metallic elements in the Wabash River for the period 1981–87, except where noted.

Metal	Lafayette (rkm 502)	Terre Haute (rkm 351)	Breed (rkm 288)	Vincennes (rkm 209)	New Harmony (rkm 83)
Arsenic	2.13	2.49	2.59	2.47	
Berylium	2.00	2.00			
Cadmium		2.13	2.00		
Chromium (Hex)	10.00	10.00	9.85	10.00	
Chromium (Tot)	11.67	12.04	11.62	10.89	
Copper	6.78[a]	7.07[a]	7.90		17.77
Iron	2,195[a]	3,754[a]	4,328.0		4,613.0
Lead	12.03[a]	13.36[a]	9.18		28.54
Manganese	122.0	209.3	223.4		
Thallium	20.0	20.00			
Nickel	6.47	8.12	8.23		
Zinc	23.98[a]	23.01[a]			
Antimony	0.80	0.60			
Selenium	1.15	1.24			
Mercury	0.12[a]	0.10[a]			0.32

[a] 1981–87.

Heavy metal concentrations have been determined sporadically by Indiana Department of Environmental Management (IDEM). As previously mentioned, copper concentrations decreased from 1977 to 1987 within the Ohio River basin, including the Wabash River at New Harmony (ORSANCO 1990b). Table 2 summarizes data from the ORSANCO study and unpublished data from IDEM. Concentrations of iron, lead, manganese, nickel, arsenic, and copper are higher at downriver stations than upriver.

The concentration of heavy metals generally increased downriver, probably as the result of coal mining activities in the lower half of the basin (Wilber et al. 1980; Peters 1981; Wangness et al. 1981a, 1981b, 1983). Only about 0.4% of the Wabash River watershed consists of mines, but the spoil banks of old, deep coal mines, as well as old and active surface mines, are the sources of appreciable quantities of arsenic, barium, cadmium, chromium, iron, lead, manganese, and nickel.

Not until the passage of the Indiana Strip Mine Law in 1968 was any serious attention directed at mining effects. This act required that all acidic material be buried and that all stripped lands be

graded and seeded, but it applied only to active mined areas and not to abandoned mines, which continue to leach acids and heavy metals into surface waters (Thomas 1978; Wangness 1982).

Commercial Resources

The Wabash and White rivers are too small and their discharges too unreliable to serve as important transportation corridors, although river boats and paddlewheelers did use these rivers seasonally in the past. Nor is there sufficient recreational boating and fishing activity to support much marina development. Only two commercially important products, other than water, are produced by the river—clams and fish.

Mollusca

Most studies of Wabash River mollusca focus on commercially valuable species of clams. No comprehensive studies of snails have been conducted. The shells of many species of clams were used in making buttons from the late 1890's through mid 1900's, when plastic replaced shell. More recently, the cultured pearl industry mills sections of shells into round seeds, which are then implanted into pearl oysters to create cultured pearls.

The Wabash River drainage was formerly occupied by over 75 species of unionid clams (Call 1900; Blatchley and Daniels 1903; Daniels 1903, 1914; Goodrich and van der Schalie 1944). During 1966 and 1967, 30 species of Unionidae were collected at 63 sites from the lower 530 km of the Wabash River and 250 km of the East Fork White River (Meyer 1968, 1974; Krumholz et al. 1970). The 10 species considered important in the commercial market made up 77.1% of the total catch (*Quadrula quadrula*, *Obovaria olivaria*, *Q. pustulosa*, *Actinonaias ligamentina*, *Amblema plicata plicata*, *Fusconaia ebena*, *F. flava*, *Megalonaias nervosa*, *Q. metanevra*, and *Tritogonia verrucosa*). Overharvesting was regarded as the main cause for depleted mussel stocks, although increased pollution from cities, industries, and agriculture was also regarded as important.

Cummings et al. (1987, 1988, 1991) reexamined the abundance and distribution of clams of the Wabash, White, and Tippecanoe rivers. They found a drastic reduction in range and abundance of many formerly common and widespread species on the upper and middle Wabash River. The three most abundant species were *O. olivaria*, *Leptodea fragilis*, and *Q. quadrula*, which made up 61% of the live mussels collected. Endangered species (Indiana list) collected live included *Cyprogenia stegaria*, *Q. cylindrica*, and *Plethobasus cyphyus*, but only the shells of 14 other rare, endangered, or extinct species were found.

Restrictions on commercial collecting methods were first instituted in April 1967 by prohibiting mechanical dredges and diving with auxiliary air supplies. Acceptable, less efficient methods of collection include handpicking, short forks, tongs, and crowfoot bar (brail). The mussel season traditionally extends from April 15 through October 31, but most mussels are taken in June, July, and August. A minimum size limit of 64 mm protects smaller shells. A $15 fee is charged for a license. Mussel harvest reports were collected by Indiana Department of Natural Resources, but were not summarized or tabulated before 1988 (Stevanage 1992).

Sales of Indiana shells totaled 2,000 tons in 1965, 4,200 in 1966, 1,080 in 1967, and less than 250 in 1968. In 1991, 690 tons valued at $1.6–3.0 million were bought by mussel buyers. The East Fork of the White River and the Wabash River accounted for 76% of the total 1991 harvest.

Extremely low river flows, which increased clam vulnerability during 1988 and 1991, combined with high prices for clam shells recently, led to a serious overharvest of clams (Flatt et al. 1992). A total of 950 mussel harvesters purchased licenses in 1991, nearly quadruple the average sold from 1982 to 1990. Clammers combed exposed areas in the Wabash and White rivers and then extended their harvest efforts into tributaries. On 11 September 1991, clam harvest on exclusively Indiana waters was officially banned for an indefinite period, a move favored by most legal musselers.

Plans for monitoring population increases are currently underway. The commercial value of Wabash River mussels is sufficient reason in itself to examine this resource in far greater detail than in the past. Past harvesting regulations have obviously been inadequate; however, the extent to which point-source and nonpoint-source pollution affects mussel populations is not so obvious.

The biological impact of the Asian clam (*Corbicula fluminea*) is unknown, but it is not as abundant in the Wabash River as it is in the Ohio River and the southeastern United States. Zebra mussels (*Dreissena polymorpha*) have not yet

reached this area but will no doubt do so soon, and resident mussels may be influenced by yet another factor.

Commercial Fishery

Inland net fishing is limited to about 900 km of the Wabash, White, and Patoka rivers and 580 km of the Ohio River (Stevanavage 1990; Blackwell 1991). The lower 325 km of the Wabash River forms the boundary between Indiana and Illinois and may be fished without limits to the numbers of nets or seines. Indiana waters, however, may be fished by a maximum of four hoop or trap nets with stretched mesh not less than 5 cm. The license is free, but metal net tags cost $4. Most of the commercial harvest is used directly by the fishermen and their families. Few fishermen, if any, derive their entire income from the river, although some fish may be sold locally.

The number of commercial licenses issued annually from 1974 to 1990 fluctuated between 800 and 400. Mandatory reporting of harvest, initiated in 1977, led to a 40% decline in licensed fishermen in 1978. In January 1985, a fish consumption advisory was issued for the Wabash River from Lafayette to Darwin, Illinois, and for the West Fork of the White River from Broad Ripple to its junction with the East Fork. This may have been the reason commercial fishing licenses declined 20%, from 605 in 1984 to 447 in 1986 (Glander 1987), and also why the overall harvest declined by about 20%. However, the most important species in the commercial catch (channel catfish and flathead catfish) increased during this period; the decrease was mainly from reduced catches of carp, suckers, and drum. Catfish species currently constitute about 70% of the harvest. This commercial increase correlates well with the increased catch of catfish by electrofishing, which will be discussed.

Phytoplankton and Primary Productivity

Interactions between the biota and the physical and chemical environment are sporadic, complex, and poorly perceived in the highly variable environment of most rivers. The entire Wabash River ecosystem seems to be strongly influenced by phytoplankton during the summer months, but there are few data to support that contention. Our knowledge about this particular group is disparate to its ecological importance. Phytoplankton is the most important producer group in the middle Wabash River. Water willow beds are well represented in the upper river, but become scarce in the lower two-thirds. Periphyton is severely limited because of the turbidity of the water.

The IDEM, formerly a Division of the Indiana State Board of Health, began collecting phytoplankton from various river stations on a monthly schedule in 1971 (Indiana State Board of Health1957–85; Indiana Department of Environmental Management 1986–90). The basic spatial pattern of phytoplankton density and the influence of variable discharge is shown best at eight stations along the Wabash River during the summers of 1977 and 1988 (Fig. 3). During summer low-flows, the density in the upper river is usually relatively low, but it increases dramatically to reach high values downriver from Lafayette. The summer of 1977 followed a dry winter and spring. Algal densities were very high in June and July, but decreased greatly when river discharge increased in August and September. Usually the phytoplankton community is dominated by diatoms, but green algae were about as important numerically as diatoms in 1988. Phytoplankton density is high during the warmer months (May–October) and low during the winter months.

During the summers of 1981 and 1982, an interdisciplinary team conducted a study of the dissolved oxygen (DO) status of the middle Wabash River (Bridges et al. 1986). Phytoplankton densities ranged from 20,000 to 120,000 cells/mL, chlorophyll *a* ranged from 18 to 247 μg/L, pheophytin *a* was 6.5 to 51 μg/L, gross primary productivity (GPP) ranged from 70 to 850 mg $C/m^2/h$, and net primary productivity was 90 to 784 mg $C/m^2/h$. Turbidity was high, and the depth of the euphotic zone was only 0.2 to 1.2 m.

Estimates were also made of point-source biological oxygen demand (BOD), sediment oxygen demand (SOD), and chemical oxygen demand (COD). All of this information was used to estimate the dissolved oxygen deficit (DOD) using a version of the DIURNAL computer model (Hydro-Qual, Inc. 1984). The DOD is calculated as the saturation concentration at the prevailing temperature minus the actual dissolved oxygen concentration (Smith et al. 1987). This model projected low-flow DOD values of 2.0 to 2.5 mg DO/L from Delphi to Montezuma and then increasing values to about 4.0 mg DO/L from Terre Haute to Merom.

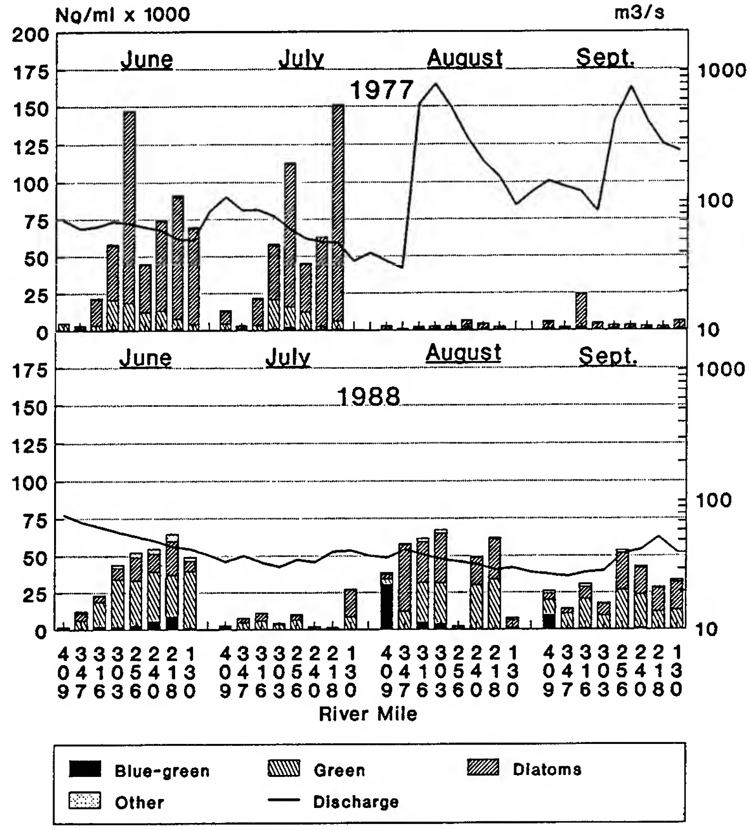

Fig. 3. Density of phytoplankton in the Wabash River during the summers of 1977 and 1988.

Phytoplankton respiration was estimated to cause 50–60% of the DOD in the upper study section and about 70% downriver from Terre Haute. The second largest source, carbonaceous BOD (CBOD), which entered the river from multiple point-sources, accounted for only about 10% of the DOD in the upper reaches and over 15% downriver from Terre Haute. Sediment oxygen demand was estimated to be the third largest oxygen sink, and nitrogenous BOD and other substances also contributed to a minor degree.

Phytoplankton and other organic substances may indirectly affect the fish community during low flows in some parts of the river by reducing dissolved oxygen concentrations (Parke and Gammon 1986). Interactions occur between river morphology, large algal populations sustained by high nutrient inputs, and thermal loading from an electric generating station to produce low DO in a 9.6-km section of river dammed by gravel from Sugar Creek. When flows diminished to about 1,500 cfs there was a sharp increase in phytoplankton density, with chlorophyll *a* increasing from about 160 μg/L to nearly 230 μg/L. Significant amounts of suspended solids settle to the bottom as the water passes through the ponded segment. Chlorophyll *a* decreased to less than 150 μg/L, and total suspended nonfiltrable solids decreased from 80 mg/L to about 50 mg/L. Secchi disk transparency increased as suspended materials settled out and SOD increased. A depression in DO led to avoidance in 1977 (Gammon and Reidy 1981) and caused fish kills in 1983 and 1986.

The DO sag was reexamined in 1988, both with and without the Cayuga Electric Generating Station operational (Yost and Rives 1990). The conclusion was that a DO sag occurs naturally because of pool morphology and high summer temperatures.

The Fish Communities of the Wabash River

The Wabash River mainstem may be divided into the headwaters upriver from Huntington Reservoir (rkm 660), the middle mainstem extending from the Huntington dam south to the mouth of White River (rkm 660–206), and the

lower mainstem from Vincennes to the Ohio River. Only in recent decades have the fish communities of the upper and middle Wabash River and its tributaries received the attention they deserve. The lower mainstem has received little attention to date.

Upper Wabash River

Indiana Department of Natural Resources studies of the upper Wabash River indicate that, while a variety of other species are present in small numbers, gizzard shad, carp, and carpsucker species constituted over 55% of numbers and 65% of the biomass of fishes in the river above Huntington Reservoir (Pearson 1975). This section of river is sluggish and ditch-like, with a surrounding landscape dominated by extensive row-crop agriculture. The mainstem and its tributaries are used primarily for the removal of excess water during the spring rainy period.

Environmental conditions and the quality of the fish community improve considerably downriver from the Huntington dam after the river enters the reservoir, which clarifies it. Assisting in the process are the entering waters of the Salamonie and Mississinewa rivers, both of which first pass through reservoirs before entering the Wabash River mainstem. Here "the river retains much of its native beauty," although algal densities sometimes color the river brownish and produce high mid-afternoon DO concentrations (Robertson 1975). The fish community between Huntington dam (rkm 658) and Covington, Indiana (rkm 436), was dominated by gizzard shad, carp, and carpsuckers (58% by numbers, 56.6% by weight), but redhorse and game fish were much more abundant (drum, sauger, smallmouth bass).

In 1989, Braun (1990) electrofished 18 stations between the Indiana–Ohio state line (rkm 746) and Peru, Indiana (rkm 590), and, upstream of Huntington Dam, found a mediocre fish population dominated by carp and white suckers. Catches of sauger were lower than in 1974, but walleye, which were first stocked into upper Wabash reservoirs in the early 1970's, had increased. Shovelnose sturgeon and spotted bass had extended their ranges northward.

Middle Wabash River

The aquatic communities of the middle Wabash River near Cayuga, Wabash River, and Breed electric generating stations have been examined thoroughly and regularly since the late 1960's. Spacial constraints prohibit discussing the results of these studies. We have studied this part of the river annually since 1967 (Gammon 1971, 1973, 1976a, 1976b, 1980, 1982, 1991; Teppen and Gammon 1975; Gammon et al. 1979; Gammon and Reidy 1981). Initial assessments of thermal effects at two power plants were expanded in 1973 to multiple stations in 160 km of river and again in 1978 to include 260 km of mainstem. Electrofishing proved to be most effective for the greatest number of large species in the Wabash River. Table 3 lists the species collected during this period and also includes smaller residents that were collected in special seining collections by Roggelin (1979) and EA Science and Technology (1988, 1989).

Each summer during daylight hours, three electrofishing samples were taken from each of 63 stations. Each station was 0.5 km long and located in relatively fast water with good cover and depths of 1.5 m or less. Each station was sampled near shore with a Smith-Root Type VI electrofisher producing 600 VDC and 60 pps. The pulsed DC was fed into an electrode system consisting of two circlets of short, stainless steel anodes suspended at the water surface by bow booms, and two gangs of long, woven copper cathodes off the port and starboard gunwales. Fish were identified to species, weighed, measured, and returned to the river unharmed. Young-of-the-year fish were excluded from computations of community and population indices. For analytic purposes, the river was divided into 12 reaches as defined in Table 4, with each reach containing five collecting stations.

Community structure differed qualitatively and quantitatively throughout the study region. However, all of the calculated community parameters exhibited the same basic pattern, high values in the upper sections declining to lower values in the lower section (Fig. 4). Because a good fish community has both an abundance of individuals and a high diversity of species, we formulated a composite index of well-being (Iwb) to quantitatively represent the fish communities from electrofishing catches (Gammon 1980). This index is calculated as follows:

$$I_{wb} = 0.5 \ln N + 0.5 \ln W + Div._{no.} + Div._{wt.}$$

where N = number of fish captured per kilometer,

W = weight in kilograms of fish captured per kilometer,

$Div._{no.}$ = Shannon diversity based on numbers, and

$Div._{wt.}$ = Shannon diversity based on weight.

A high Iwb value is indicative of an excellent fish community, which also exhibits relatively high values for diversity, abundance, number of sport fishes, and percent biomass insectivores and relatively low biomass of carp and gizzard shad (Table 5). A low Iwb value characterizes a poor fish community with the opposite attributes. Good and fair communities are intermediate. Values of Iwb were highly correlated with the average number of species taken at each site. The long-term studies have permitted us to (1) document recent overall improvements in the fish community, (2) identify problem sections of the river, (3) evaluate ecological changes associated with operational alterations by industry, (4) discriminate between natural and man-induced effects, and (5) clarify ecological interactions among the major biotic components of the riverine community.

The improvement in the fish community in the Wabash River from 1973–75 to 1984–92 was statistically significant (Table 6). Numeric and biomass catch rates increased markedly, Shannon–Weiner diversities and Iwb values increased substantially, and evenness values rose slightly. Numeric and biomass catch rates displayed the same pattern over time, although there was a much greater variability in numbers than biomass (Fig. 5). The changes in other community parameters were even more prominent (Fig. 6). Post-1983 values for the Iwb and both Shannon–Weiner indices of diversity increased, as did the mean number of species captured per collection.

Most species populations, except for carp and gizzard shad, expanded significantly. For example, from 1974 through 1983 the combined catch rate of sport fishes averaged slightly more than 2.0/km and then more than quadrupled during 1984–87 (Fig. 7). Many other species of fish also increased, especially in the upper river. Most species of fish that reproduced and lived in the mainstem in-

Table 3. List of fish species collected from the middle Wabash River from 1967 to 1992.

Family Common name	Scientific name
Lamprey family—Petromyzontidae	
Silver lamprey	*Ichthyomyzon unicuspis* Hubbs and Trautman
American brook lamprey	*Lampetra appendix* (DeKay)
Sturgeon family—Acipenseridae	
Shovelnose sturgeon	*Scaphirhynchus platorynchus* (Rafinesque)
Paddlefish family—Polyodontidae	
Paddlefish	*Polyodon spathula* (Walbaum)
Gar family—Lepisosteidae	
Spotted gar	*Lepisosteus oculatus* (Winchell)
Longnose gar	*L. osseus* (Linnaeus)
Shortnose gar	*L. platostomus* Rafinesque
Bowfin family—Amiidae	
Bowfin	*Amia calva* Linnaeus
Mooneye family—Hiodontidae	
Goldeye	*Hiodon alosoides* (Rafinesque)
Mooneye	*H. tergisus* Lesueur
Freshwater Eel family—Anguillidae	
American eel	*Anguilla rostrata* (Lesueur)
Herring family—Clupeidae	
Skipjack herring	*Alosa chrysochloris* (Rafinesque)
Gizzard shad	*Dorosoma cepedianum* (Lesueur)
Minnow family—Cyprinidae	
Central stoneroller	*Campostoma anomalum* (Rafinesque)
Goldfish	*Carassius auratus* (Linnaeus)
Spotfin shiner	*Cyprinella spiloptera* (Cope)
Steelcolor shiner	*C. whipplei* Girard
Common carp	*Cyprinus carpio* Linnaeus
Mississippi silvery minnow	*Hybognathus nuchalis* Agassiz

Table 3. *Continued.*

Family Common name	Scientific name
Striped shiner	*Luxilus chrysocephalus* (Rafinesque)
*Redfin shiner	*Lythrurus umbratilis* (Girard)
*Speckled chub	*Macrhybopsis aestivalis* (Girard)
Silver chub	*M. storeriana* (Kirtland)
River chub	*Nocomis micropogon* (Cope)
*Golden shiner	*Notemigonus crysoleucus* (Mitchill)
Bigeye chub	*Notropis amblops* (Rafinesque)
Emerald shiner	*N. atherinoides* Rafinesque
*River shiner	*N. blennius* (Girard)
*Ghost shiner	*N. buchanani* Meek
Silverjaw minnow	*N. buccata* Cope
Rosyface shiner	*N. rubellus* (Agassiz)
Sand shiner	*N. stramineus* (Cope)
*Mimic shiner	*N. volucellus* (Cope)
Suckermouth minnow	*Phenacobius mirabilis* (Girard)
Bluntnose minnow	*Pimephales notatus* (Rafinesque)
Bullhead minnow	*P. vigilax* (Baird and Girard)
*Blacknose dace	*Rhinichthys attratulus* (Hermann)
Creek chub	*Semotilus atromaculatus* (Mitchill)
Sucker family—Catostomidae	
Northern river carpsucker	*Carpiodes carpio* (Rafinesque)
Quillback carpsucker	*C. cyprinus* (Lesueur)
Highfin carpsucker	*C. velifer* (Rafinesque)
White sucker	*Catostomus commersoni* (Lacepede)
Blue sucker	*Cycleptus elongatus* (Lesueur)
Northern hog sucker	*Hypentelium nigricans* (Lesueur)
Smallmouth buffalo	*Ictiobus bubalus* (Rafinesque)
Bigmouth buffalo	*I. cyprinellus* (Valenciennes)
Black buffalo	*I. niger* (Rafinesque)
Spotted sucker	*Minytrema melanops* (Rafinesque)
Black redhorse	*Moxostoma duquesnei* (Lesueur)
Golden redhorse	*M. erythrurum* (Rafinesque)
Silver redhorse	*M. anisurum* (Rafinesque)
Shorthead redhorse	*M. macrolepidotum* (Lesueur)
River redhorse	*M. carinatum* (Cope)
Catfish family—Ictaluridae	
Black bullhead	*Ameiurus melas* (Rafinesque)
Yellow bullhead	*A. natalis* (Lesueur)
Blue catfish	*Ictalurus furcatus* (Lesueur)
Channel catfish	*I. punctatus* (Rafinesque)
Stonecat	*Noturus flavus* Rafinesque
*Mountain madtom	*N. eleutherus* Jordan
*Brindled madtom	*N. miurus* Jordan
*Freckled madtom	*N. nocturnus* Jordan & Gilbert
Flathead catfish	*Pylodictis olivaris* (Rafinesque)
Pike family—Esocidae	
Grass pickerel	*Esox americanus* Gmelin
Codfish family—Gadidae	
Burbot	*Lota Lota* (Linnaeus)
Killifish family—Cyprinodontidae	
Blackstripe topminnow	*Fundulus notatus* (Rafinesque)
Silversides family—Atherinidae	
*Brook silversides	*Labidesthes sicculus* (Cope)
Temperate Bass family—Percichthyidae	
White bass	*Morone chrysops* (Rafinesque)

Table 3. *Continued.*

Family Common name	Scientific name
Yellow bass	*M. mississippiensis* Jordan and Eigenmann
White bass × striped bass hybrid	
Sunfish family—Centrarchidae	
Rock bass	*Ambloplites rupestris* (Rafinesque)
Green sunfish	*Lepomis cyanellus* Rafinesque
Pumpkinseed	*L. gibbosus* (Linnaeus)
*Orangespotted sunfish	*L. humilis* (Girard)
Longear sunfish	*L. megalotis* (Rafinesque)
Warmouth	*L. gulosus* (Cuvier)
Bluegill	*L. macrochirus* Rafinesque
Redear sunfish	*L. microlophus* (Gunther)
Smallmouth bass	*Micropterus dolomieu* Lacepede
Spotted bass	*M. punctulatus* (Rafinesque)
Largemouth bass	*M. salmoides* (Lacepede)
White crappie	*Pomoxis annularis* Rafinesque
Black crappie	*P. nigromaculatus* (Lesueur)
Perch family—Percidae	
Greenside darter	*Etheostoma blennioides* Rafinesque
Rainbow darter	*E. caeruleum* Storer
*Fantail darter	*E. flabellare* Rafinesque
Johnny darter	*E. nigrum* Rafinesque
*Orangethroat darter	*E. spectabile* (Agassiz)
Logperch	*Percina caprodes* (Rafinesque)
*Blackside darter	*P. maculata* (Girard)
Slenderhead darter	*P. phoxocephala* (Nelson)
*Dusky darter	*P. sciera* (Swain)
*River darter	*P. shumardi* (Girard)
Sauger	*Stizostedion canadense* (Smith)
Walleye	*S. vitreum* (Mitchill)
Drum family—Sciaenidae	
Freshwater drum	*Aplodinotus grunniens* Rafinesque

*Species collected with a seine during special studies (Rogellin 1979; EA Science and Technology 1988, 1989).

Table 4. Location of study reaches of the Middle Wabash River.

Reach	River km	River mile	Description of location
1	531–502	329–311	Delphi to north Lafayette, Indiana
2	501–486	312–302	Lafayette-West Lafayette area
3	485–460	301–286	Lafayette to Attica, Indiana
4	459–433	285–269	Attica to Covington, Indiana
5	432–404	268–251	Covington to Coal Creek
6	402	249.6	Cayuga Electric Generating Station
7	396–375	247–233	Cayuga EGS to Eli Lilly, Clinton
8	374–351	232–218	E.L. Clinton to Otter Creek
9	347	215.4	Wabash Electric Generating Station
10	343–327	213–203	Terre Haute, Indiana area
11	325–299	202–186	Terre Haute STP to Darwin, Illinois
12	298–257	185–160	Darwin, Illinois to Merom, Indian

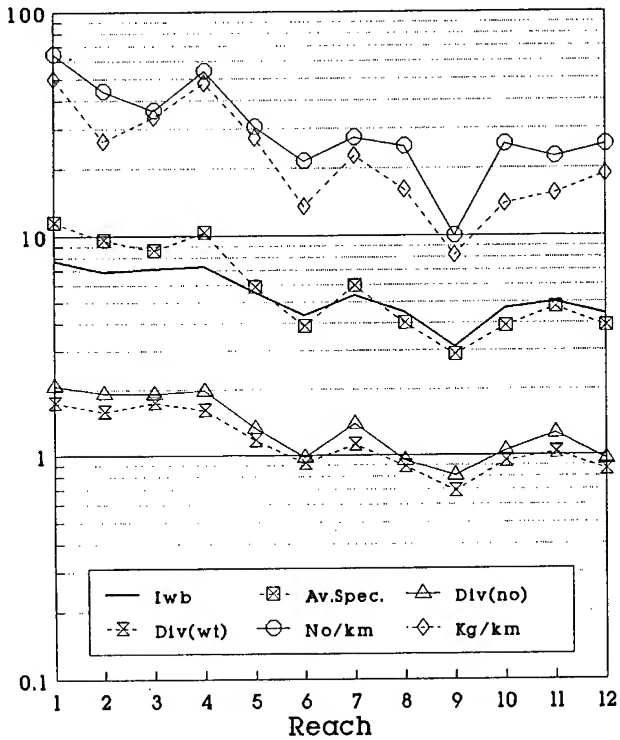

Fig. 4. Spatial pattern of community indices in the middle Wabash River in 1988.

creased greatly in density throughout the river, (e.g., channel catfish, flathead catfish, sauger, spotted bass, mooneye, goldeye, northern river carpsucker, blue sucker, and drum). Some species populations expanded their ranges into previously unoccupied areas of the river. Blue sucker catches tripled as they became established in the upper (1–4) and lower (9–12) reaches. Mooneye, sauger, smallmouth bass, and spotted bass became important components of catches in reaches 1–4. Goldeye and shortnose gar increased mainly in the lower reaches.

Increased catches also occurred for some species that entered the mainstem primarily from offstream reservoirs (white bass and walleye) and from clean tributaries (smallmouth bass and longear sunfish). Carp and gizzard shad populations declined, however, perhaps owing to the increased predator pressure from expanded piscivore populations.

The average size of many species increased despite growing numbers of recruits, raising questions of greater longevity or faster growth, possibilities that remain to be explored. There was a noticeable increase in the length frequency distribution of gizzard shad as the enlarged predator population exerted control. By 1991, predator populations had decreased sufficiently to again permit gizzard shad to produce a large year class, with the result that the 1992 catch of gizzard shad was as large as that of the previous 5 years combined.

The most remarkable phenomenon was how quickly the entire community changed. The 1983

Table 5. Community parameters and qualitative evaluations of fish communities.

Parameter	Excellent	Good	Fair	Poor
Community				
Index of well-being	> 8.5	7.0–8.5	5.5–7.0	< 5.5
Average number of species	> 15.0	8–15	5–8	< 5.0
Number/km	> 100.0	60–100	25–60	< 25.0
Kg/km	> 50.0	25–50	15–25	< 15.0
Div. (no.)[a]	> 2.2	1.7–2.2	1.3–1.7	< 1.3
Div. (wt.)[b]	> 2.0	1.5–2.0	1.1–1.5	< 1.1
Even (no.)	0.75–0.90	0.75–0.90	0.75–0.90	0.75–0.90
Even (wt.)	0.70–0.80	0.70–0.80	0.70–0.80	0.70–0.80
Sport fish[c]				
Number/kilometer	> 20	12–20	4–12	< 4
Trophic Composition				
Percent weight piscivores	15–30	15–30	15–30	15–30
Percent weight insectivores	> 30	15–30	5–15	< 5
Percent weight herbivores	< 10	10–20	10–20	> 20
Percent weight detritivores	> 5	2–5	1–5	< 1
Percent weight omnivores[d]	< 40	< 40	40–60	> 60

[a] Shannon diversity based on numbers.
[b] Shannon diversity based on weight.
[c] Centrarchid bass, white bass, catfish, sauger, walleye, sunfish, and crappie.
[d] Carp exclusively in this study.

Table 6. Statistical changes in the values of fish community parameters (mean and S.E.) from 1973–83 to 1984–92.

Community index	1973–83		1984–92		*t*-test	Percent change
Number/km	29.93	(0.77)	51.09	(1.42)	1.83	+70.7
Kg/km	13.43	(0.34)	22.18	(0.46)	3.81**	+65.2
Number species per collection	4.93	(0.07)	6.88	(0.09)	3.11**	+39.6
S-W diversity (no.)	1.097	(0.014)	1.399	(0.015)	3.33**	+27.5
S-W diversity (wt.)	1.002	(0.013)	1.314	(0.013)	3.90**	+31.1
Evenness (no.)	0.71	(0.007)	0.76	(0.057)	1.41	+ 7.0
Evenness (wt.)	0.65	(0.006)	0.71	(0.004)	3.79**	+ 9.2
Index of well-being	4.64	(0.043)	5.86	(0.041)	4.01***	+26.1

**P<0.01.
***P<0.001.

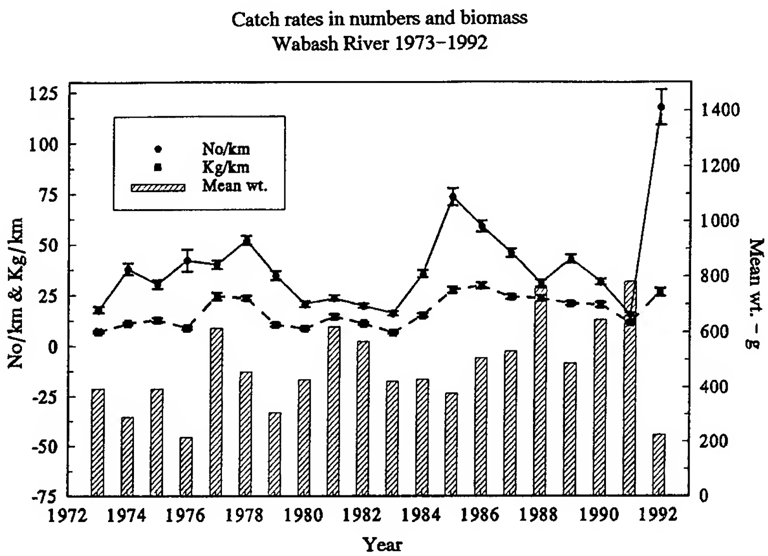

Fig. 5. Total annual catch rates (mean and S.E.) in number per kilometer and kilogram per kilometer and mean weight of fish caught from 1973 through 1992.

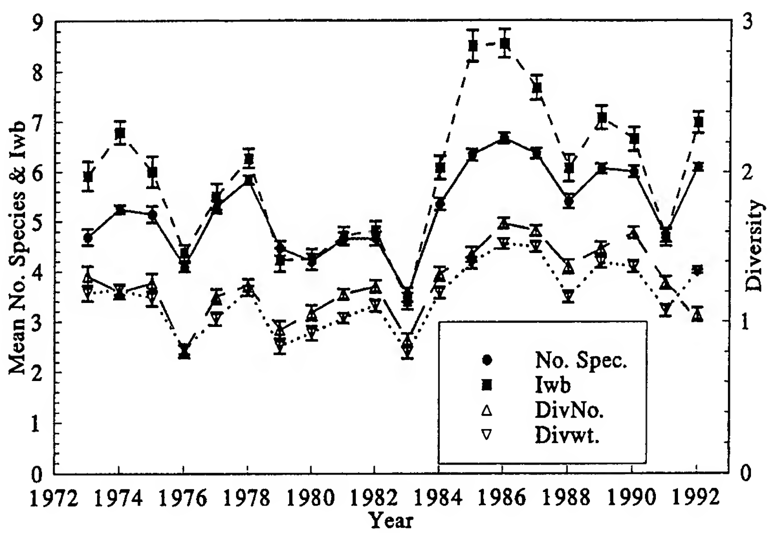

Fig. 6. Mean number of species per collection, index of well-being, and Shannon-Weiner diversities by numbers and biomass based on total annual catches from 1973 through 1992.

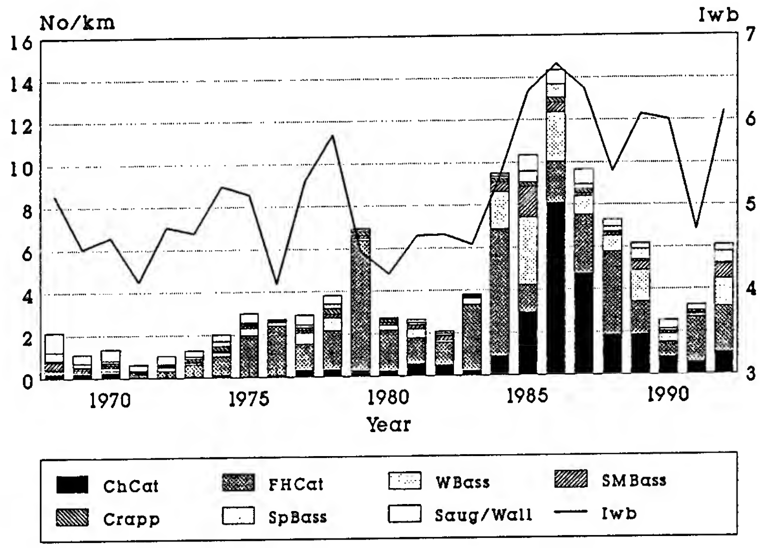

Fig. 7. Annual catch rates of some sportfishes and index of well-being from 1973 through 1992.

catches were dismal. Two years later catches were outstanding (Fig. 8) and, while the quality of the community gradually diminished, it remained much better until 1990. Perhaps the drought conditions of 1991 will promote another boom in the community. Catches during the 1988 drought were depressed only in the lower reaches, whereas those during 1991 were noticeably depressed throughout the entire middle river (Fig. 9).

The recent improvements in the fish community probably resulted from a combination of events, including a long-term 50% reduction in BOD loading, the result of improvements in industrial and municipal waste treatment during the 1970's and early 1980's. The summer of 1983 was a low-flow summer, which has been shown statistically to facilitate good reproduction and survival through the first year for most mainstem species of fish. That most significant year was also the year of the Payment In Kind (PIK) program, when farmers were paid not to grow crops. In Indiana this led potentially to a 25% reduction in agricultural loadings to the river (i.e., 25% fewer acres of corn and soy beans were tilled).

The fish data have also aided in evaluating the effectiveness of changes in procedures for waste treatment. For example, when an electric generating station (reach 6) began operating its cooling facilities continuously at ambient river water temperatures of 25.6° C, the Iwb improved in that reach, although it declined in all other reaches. Furthermore, there was a return to the area of several species that had not been common for many years—smallmouth buffalofish, redhorse, blue sucker, and sauger.

The fish community was usually stable during the entire summer and into fall, so sampling variability was usually not dependent on timing of sampling. However, large changes because of stress sometimes occurred within a few weeks (Gammon and Reidy 1981). Based on the changes in fish communities we have seen, monitoring frequency should be no less than every 2–3 years. Major shifts in population size and community structure would have been missed at longer intervals. Multivariate statistical analysis of the data is currently underway.

In summary, the fish community of the middle Wabash River has demonstrated an unexpected

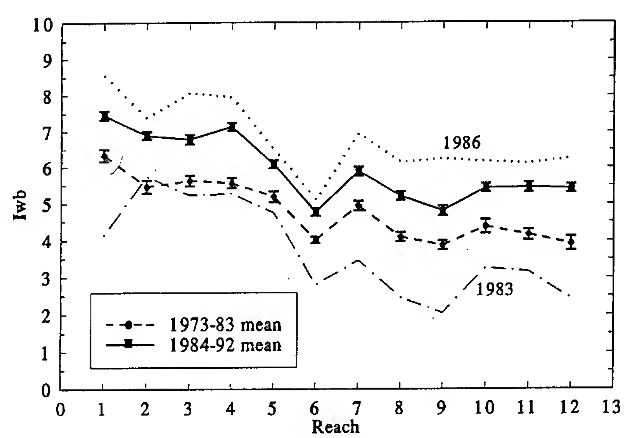

Fig. 8. Comparison of the spatial patterns of index of well-being values (mean and S.E.) for the periods 1973–83 and 1984–92.

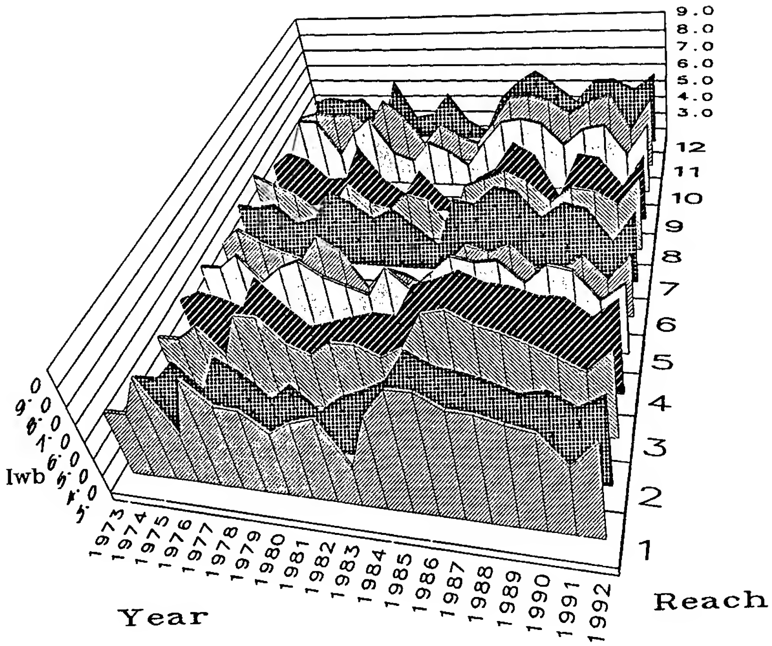

Fig. 9. Summary of changes in the index of well-being values over time and space from 1973 through 1992.

capacity for improvement. That improvement seems to be linked to reduced BOD inputs and better dissolved oxygen conditions. Phytoplankton populations exceeding 100,000 cells/mL during the summer cause DO problems and contribute to high turbidities. Further improvements in the fish community seem to be contingent on reducing nutrient inputs.

Acknowledgments

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Fish-Habitat Associations and Sport Fishing Opportunities in the Little Wabash River Watershed in Southeastern Illinois

by

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Abstract. In 1989, we collected fish from streams within the Little Wabash River basin in southeastern Illinois to assess fish composition, stream quality, and availability of sport fish for anglers. Seventy-four species were collected from 45 sampling locations on 15 streams. According to a modified form of Karr's Index of Biotic Integrity (IBI), stream quality at wadable sites ranged from 29.4 to 51.3; the highest ratings were in the upper part of the watershed (IBI values >40). Values at boat sites ranged from 29.4 to 44.7; the upper part of the mainstem and upper Skillet Fork achieved the highest scores. In addition to their greater overall biotic integrity, samples from wadable sites in the upper portion of the watershed were more closely associated with each other than with samples from other wadable sites. Based on these major community groups, several physical features, including substrate composition, instream cover, mean width of water, and percent of pool and run habitat, were significantly different ($P < 0.05$) between some of these groups. Changes in substrate composition, as a part of geological differences between the upper and lower watershed, seem to influence the fish community. Discharge variability, as indicated by the coefficient of variation, showed greater variability from downstream to upstream. At boat sites, four community groups were delineated, but only mean percent shading was significantly different between any of the four groups. On the mainstem, availability of two major sport fish, spotted bass (*Micropterus punctulatus*)

and channel catfish (*Ictalurus punctatus*), varied longitudinally. Spotted bass were observed primarily in the upper and lowermost reaches, while channel catfish were most common in the middle and lower stations. Overall, white crappie (*Pomoxis annularis*) and largemouth bass (*Micropterus salmoides*) occurred in low numbers in both the mainstem and tributaries. Bluegill (*Lepomis macrochirus*) occurred throughout the watershed, with larger individuals further downstream on the mainstem. Common carp (*Cyprinus carpio*) were generally distributed in the mainstem and only collected occasionally in tributaries.

Temporal and spatial scales are essential in understanding the associations between biological and physical attributes of a system. As noted by Wiens (1989), these features need to be considered with respect to the organisms being studied. For fish, associations with habitat have been evaluated over a wide range of spatial scales from microhabitat (Ross et al. 1987) through ecoregion (Lyons 1989). Microhabitat studies may provide detailed information yet may not be widely applicable. In comparison, ecoregions, as developed by Omernik (1987), may be useful in broadscale applications (Lyons 1989; Hughes et al. 1990), but their value for classification or management of smaller geographic areas seems limited because of the inability to discriminate subtle changes in land use or geography.

The relationships between physical features and biological components within streams were recognized by Frissell et al. (1986), who developed a hierarchical classification that considers temporal and spatial scales on a watershed level. Because physical features of streams are influenced by the watersheds they drain (Hynes 1970), evaluation of watersheds provides a useful scale for assessing influences of land use and modifications to drainage systems. Because of its geological and biological diversity (Neely and Heister 1987), this approach is useful in evaluating Illinois fish resources.

Rivers and streams have been an important component in the economic development of Illinois, which has over 41,936 km of waterways (Illinois Department of Conservation-IDOC, Illinois Streams Information System-ISIS, Springfield, Illinois, unpublished data). Yet, as a consequence of these uses, as well as from direct modifications (e.g., channelization, dams), the biological and physical integrity of many of these streams has been degraded (Smith 1971; Karr et al. 1985). Stream modifications and pollution have been attributed to changes in fish composition of streams of east-central Illinois (Larimore and Smith 1963). In agricultural watersheds, the loss of habitat diversity through channelization (Portt et al. 1986) and siltation (Berkman and Rabeni 1987) negatively affect fish production or community composition. Ongoing changes in land use and future demands for water are likely to continue to adversely affect fish resources.

Since 1981, fish resource assessments have been conducted by the IDOC in small-stream systems within Illinois using the watershed scale. In 1989, as part of this ongoing effort, we sampled streams of the Little Wabash River drainage in southeastern Illinois. This study was initiated to evaluate fish community composition and habitat features associated with these communities, to characterize stream quality, and to assess sport fish opportunities.

Methods and Materials

Background

Early efforts to assess fish distribution in the Little Wabash River watershed were made by Forbes and Richardson (1920), who found 56 species. Because of taxonomic changes, this value probably underestimates the actual number based on current classification schemes. In their 1962 survey, Fisher and Smith (1963) found 51 fish species at 16 sites, but in a subsequent comprehensive review of Illinois streams, Smith (1971) noted a much richer fish fauna of 78 species. In this later assessment, Smith indicated the highest quality streams were in the upper portion of the basin. Despite this watershed's rich ichthyofauna, only a few aquatic studies, including an assessment of food habits of spotted bass (*Micropterus punctulatus*) from the Little Wabash and nearby drainages (Smith and Page 1969) and a survey of freshwater mussels (Cummings et al. 1989), have been conducted in this area. Following Smith's 1971 evaluation, fish were surveyed in 1976 (Fisher and Lockart, IDOC, Aledo, Illinois,

unpublished data), but this effort was confined to the mainstem. A 1979 environmental impact statement, addressing the development of a reservoir near Louisville (U.S. Army Corps of Engineers 1979), was mostly compiled from previous collections from various sources, including the IDOC, and provided limited information regarding methodology and relative abundance.

Since 1978, one IDOC monitoring site on the Little Wabash and one on Skillet Fork have been sampled, but despite the potential for assessing temporal changes, these sites do not provide specific information regarding spatial variation with relation to smaller tributaries or the mainstem. Thus, current, comprehensive information on the fish resources of this watershed was sparse.

Study Area

From its headwaters south of Mattoon, the Little Wabash River flows south and east for 382 km (ISIS, Springfield, Illinois, unpublished data), ultimately becoming a seventh-order (Strahler 1957) river before emptying into the Wabash River near New Haven, Illinois (Fig. 1). In combination with its largest tributary, Skillet Fork, the Little Wabash River basin encompasses 8,298 km^2, of which the Skillet Fork basin accounts for 2,749 km^2 (Healy 1979). Stream gradient is 0.38 m/km; the highest rate of fall (1.1 m/km) is in the upper 64 km (Barker et al. 1967).

Various modifications have been made to streams of this watershed; many smaller tributaries have been straightened. Channelization has been conducted on 9.5 km (2.5%) of the Little Wabash River and on 31.6 km (19.5%) of Skillet Fork (ISIS, Springfield, Illinois, unpublished data). Much of this work was completed around 1920, but was resumed in the 1960's (Barker et al. 1967). On the mainstem, six dams of varying height impound reaches of the river, primarily for recreation or as a water supply for nearby municipalities. On the tributaries, one dam is located on Skillet Fork and another on the Fox River (Fig. 1). Another dam on a small tributary near Effingham forms Lake Sara. Raised instream crossings (fords) on Skillet Fork and the Fox River impound water, but like the dams on the Little Wabash allow "run of the river" flow.

The headwaters of the mainstem originate in the Shelbyville Moraine (Forbes and Richardson 1920; Bier 1980), and the entire watershed lies within the Till Plains section of the Central Lowland Province (Zeuhls 1987). Within this section, the mainstem traverses three physiographic divisions, including the Bloomington Ridged Plain, Springfield Plain, and Mount Vernon Hill Country (Fig. 2). Substantial rock outcroppings can occur along the river. Soil types are variable, having been developed from loess in the uplands, with soils in the river valleys derived from alluvium and glacial outwash (Zeuhls 1987). Though varying with type, most soils are acidic (pH 4.0–7.8); the more neutral to basic soils range from 5.1 to 9.0. Productivity is moderate to low (Zeuhls 1987), yet land use is dominated by cash-crop agriculture (IDOC–LUDA data, Springfield, Illinois, unpublished). Livestock (cattle, hogs) and petroleum products, primarily oil and natural gas (Neely and Heister 1987), are also major economic endeavors. Urban development is sparse, with Effingham (11,851), Olney (8,664), Carmi (5,564), and Fairfield (5,439) among the largest population centers.

Site Selection and Fish Collection

We selected sites based on several criteria, including IDOC and Illinois Environmental Protection Agency (IEPA) historical records. Attempts were made to include representative habitat features (e.g., large riffles, pools) and to provide broad spatial distribution. At sites sampled, stream order ranged from 3 to 7. Sites were denoted using the IEPA hierarchical, alphanumeric code. For example, letter codes were established based on the stream's position within the watershed. The mainstem was denoted as "C" and the first stream up from the mouth was denoted as "CA." Station numbers were assigned as sites were established. Thus, because of previously sampled locations, these were not always in longitudinal order within any specific stream.

Wadable sites were sampled with an electric seine (Bayley et al. 1989; Dowling et al. 1990) powered by a 1,600-W single-phase generator. This gear was hauled through the stream followed by three netters, who attempted to collect all stunned fish. No block nets were used. Station length ranged from 87 to 273 m and endeavored to include major habitat features (e.g., pools, riffles, logjams). Most sites were sampled for 30 min.

Nonwadable sites were sampled with a boat-mounted electrofishing unit powered by a 180-cycle, 3,000-W generator. A person at the bow and the engine operator netted fish. Sampling effort at these sites ranged from 30 to 60 min. When feasible, this effort was supplemented with minnow seine hauls in shallow areas. For this sampling, the net

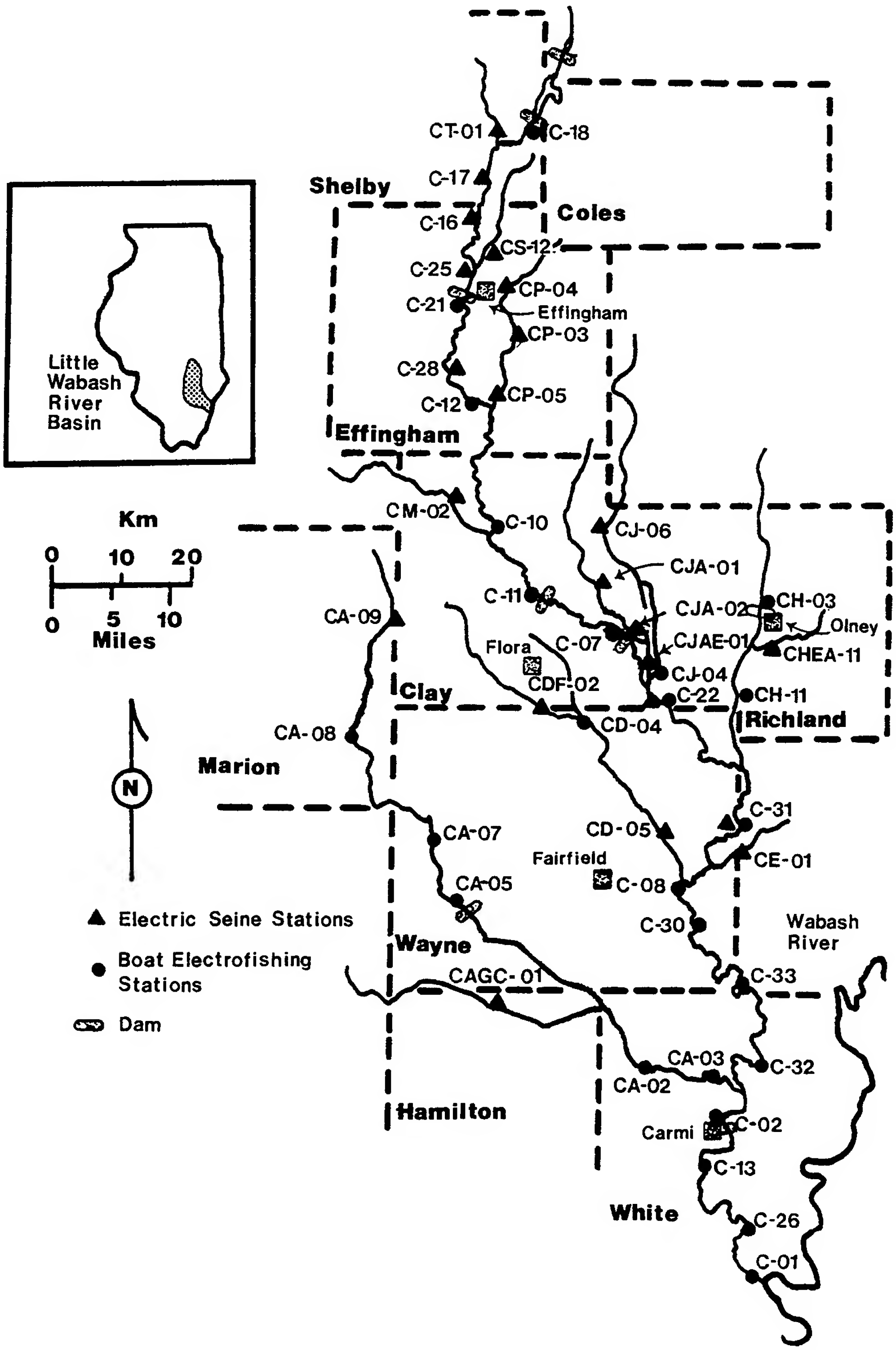

Fig. 1. Map of the Little Wabash River watershed. Sites are designated using Illinois Environmental Protection Agency codes.

was either pulled through the water or, in riffles, held in place and fish directed toward the net by kicking and turning rocks upstream of the net. Both electrofishing methods were used at two mainstem sites, C-22 and C-31, where depth in large riffle areas was suitable for sampling with the electric seine.

Field measurements of fish lengths were recorded to the nearest millimeter. Most fish were weighed to the nearest 5 g, but because of the wide range in fish sizes, several weighing scales with varying precision were used. Fish not measured in the field were preserved in formalin and later identified in the laboratory using Pflieger (1975), Smith (1979), and Becker (1983). For these fish, length and weight were recorded for individuals, or fish were placed in 10-mm-length groups (five or more fish in a 10-mm group). In some samples, for species with high abundances (usually >100 fish), length and weight were taken on a representative subsample, and the remaining fish were counted and weighed collectively.

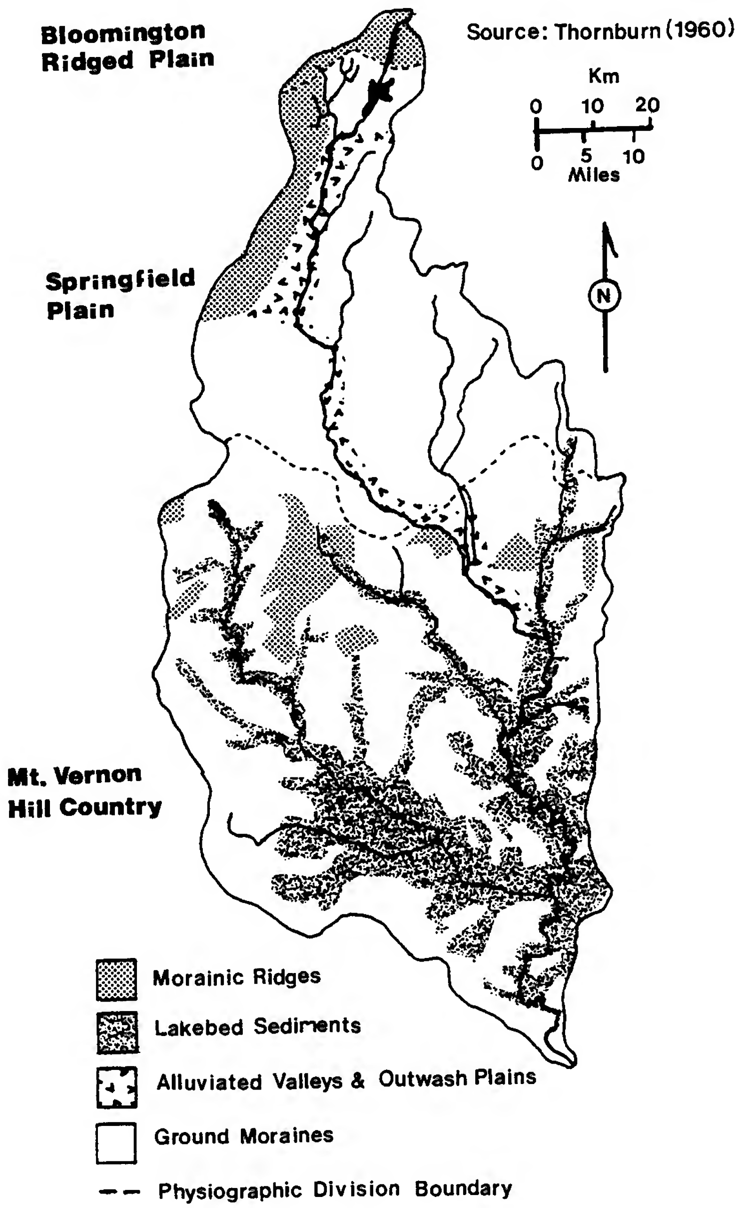

Fig. 2. Geological features of the Little Wabash River watershed.

Habitat and Water Quality Data

At wadable sites, where mean depth was typically less than 0.46 m, habitat (e.g., substrate composition, instream cover of logs, brush) was measured at the time of fish collection. For these collections, 11 equally spaced transects were established perpendicular to stream flow, within the reach from which fish were collected (IEPA 1987). Equally spaced points (usually 10, but was contingent upon stream width) along each transect were sampled for depth and substrate composition. Discharge was measured using standard U.S. Geological Survey (USGS) methodology (Hite et al. 1992). Water samples were collected and analyzed by the IEPA using procedures discussed in the IEPA methods manual (IEPA 1987). These collections were made during spring, summer (during the fish collection period), and fall. Water samples were analyzed for basic physical features, nutrients, and heavy metals. For our analysis, we selected those constituents (e.g., water temperature, turbidity, conductivity, dissolved oxygen, unionized ammonia, total nitrogen) that we believed most relevant to fish populations. Because of limited availability of personnel, habitat data were measured only at wadable sites (i.e., electric seine; 21 sites), while water quality was collected at 43 of the 45 sites. At nonwadable sites (i.e., boat sites), major substrate types, stream width, shading, and depth were estimated by IDOC personnel. Thus, these data represent a qualitative assessment. In comparison to wadable sites, fewer substrate categories were also recorded at boat sites (e.g., one category of sand compared to fine and coarse sand at wadable sites).

Annual patterns in flow and turbidity (NTU) were obtained from USGS publications (1980–90). A longitudinal perspective was provided by using gage data from the stations at Effingham (upper), Clay City (middle), and Carmi (lower).

Data Analysis

For community similarity analyses, electric seine and boat electrofishing samples were assessed separately because of differences in sampling efficiencies of the two gear types. Use of each method also represents differences in habitat, especially depth. Minnow seine data were used only in length classification of sport fish and in calculation of the Index of Biotic Integrity (IBI). Additional community comparisons were made with Horn's Index (Horn 1966). For this index, fish abundance values from electrofishing samples were converted to relative abundance (number per hour) to allow a comparison between stations where differences occurred in sampling time. These values were then incorporated, using Eckblad (1989), into an unweighted multiple pair-group analysis (UMPGA; Sneath and Sokal 1973) and used to develop a dendrogram. Hybrid sunfish, though not classified to the same taxonomic level as other fish, were included in the analyses because this group has potential biological importance as an indicator of habitat degradation (Karr et al. 1986). We observed a distributional pattern in the communities based upon the location within the watershed or stream. This distributional pattern corresponded to a coefficient of similarity of 0.55 or greater. Despite its subjectivity, we believe this level is appropriate and delineates major community groups. Much higher levels of similarity are likely to represent only slight differences in communities based upon uncommon taxa or differences in abundances of common taxa. Lower levels of similarity would not allow distinction between clusters with substantially different communities. A taxon was considered characteristic of a group if it had a relative abundance of at least two and occurred in 75% of the stations within that community group.

The IBI, as outlined by Karr et al. (1986), characterizes stream quality according to the fish community. We employed a slightly modified form of the IBI, adapted for Illinois streams by Hite and Bertrand (1989), in which the mean of the other 11 metrics is used for the condition metric, when disease information is not known. In situations where more than one sampling method was used at a site (e.g., boat sites with supplemental seine hauls), we calculated a mean of the abundance metric for both methods. At C-22 and C-31, where both electrofishing methods were used, we calculated IBIs based on each method because our analysis is by method. Actual number of fish was used for this analysis. We used a paired *t*-test (Zar 1984) to compare IBI values at sites sampled in 1976 and 1989.

Angling opportunities were evaluated by placing several sport fish species into length categories according to Gabelhouse (1984). With the exception of common carp, frequently low numbers or inconsistent collection of quality size fish or greater precluded the consistent application of a stock index such as proportional stock density (PSD; Anderson 1978). However, the number of

fish less than stock length (L) and in the stock length (S) category may be useful in denoting future sport fishing opportunities or nursery areas.

Habitat data, based on percent composition (e.g., substrate, pool, riffle), were square root arcsine transformed before analysis (Zar 1984) and converted from radian to degree values. For use in comparison with habitat, fish variables (i.e., relative abundance, number of species) were log transformed [log(x+1)].

We used the characterization of the IEPA by Hite et al. (1992) to assess water quality. Their assessment was based on Illinois Pollution Control Board Standards and the Water Quality Index (WQI), which was calculated from the U.S. Environmental Protection Agency STORET data base. Variables of WQI include temperature, dissolved oxygen, pH, total phosphorus, total suspended solids, conductivity, unionized ammonia, and metals toxicity. The cumulative score for WQI ranges from 0 to 100; higher values indicate a greater degree of degradation. Values less than 30 indicate little or no impairment, while values greater than 70 imply moderate to severe degradation. A total WQI value for each sampled station was developed using the three seasonal water quality samples (Hite et al. 1992).

Discharge variability from three mainstem gaging stations was evaluated using the coefficient of variation (Zar 1984) of daily values for all of 1979–89.

To evaluate fish–habitat associations, we grouped habitat variables according to the distribution of stations within major clusters of the respective dendrograms. Group means were compared using an analysis of variance (ANOVA) and Tukeys HSD multiple comparison test ($P \leq 0.05$; Wilkinson 1988).

Results

Fish Abundance

Seventy-four fish species, including the state endangered spotted sunfish, and one taxon of hybrid sunfish were collected from this sampling effort (Table 1). Based on combined electrofishing methods, the most abundant species was longear sunfish (16.3%), followed by bluntnose minnow (11.5%) and common stoneroller (6.9%). Among sportfish, bluegill (5.9%), spotted bass (2.7%), and common carp (2.0%) were most common.

The 22 wadable (electric seine) stations yielded 57 species and hybrid sunfish. Longear sunfish (17.1%) and headwater species such as bluntnose minnow (13.5%), common stoneroller (8.3%), and silverjaw minnow (6.5%) were highest in abundance (Table 1).

Sixty-three species and hybrid sunfish were collected from 25 boat (nonwadable) electofishing stations (Table 1). Though longear sunfish (12.4%) and bluegill (12.64%) were likewise abundant at these sites, gizzard shad (14.2%) was most abundant. At electric seine sites this species accounted for only 1.1% of the total catch. Indicative of habitat differences at nonwadable sites, compared with wadable sites, larger-bodied species such as common carp (9.5%), freshwater drum (6.1%), and smallmouth buffalo (5.2%) were among the most common fish (Table 1).

Forty-five species were collected with the minnow seine. Only the ghost shiner and slough darter were collected with this method and not with either electrofishing technique.

Fish Communities

Wadable Sites

At wadable sites four major clusters or community groups were evident (Fig. 3), of which bluegill and green sunfish were common to all groups. Group 1 contained stations from the lower part of two tributaries that empty into the middle portion of the mainstem, while Group 2 communities were similarly from the middle reach of the mainstem and adjacent tributaries (Fig. 3). In addition to bluegill and green sunfish, several species were common to Group 1 and 2 communities, including gizzard shad, bullhead minnow, steelcolor shiner, and channel catfish (Table 2). Significantly more channel catfish were collected at Group 2 stations than any of the other groups (Table 3). Differences in species composition included the presence of common carp, blackside darter, and freshwater drum in Group 1 and not Group 2, while suckermouth minnow, bluntnose minnow, and spotted bass were more common to Group 2. In comparison with Groups 3 and 4, the steelcolor shiner was also characteristic of these mid-river stations.

Wadable Group 3 stations were most often in the upper reaches of each represented stream or were in smaller streams (Fig. 3). Longear sunfish, along with blackstripe topminnow, yellow bullhead, and pirate perch, were typical of these stations (Table 2).

Table 1. Percent composition of fish collected by each electrofishing method. Species are sorted in descending order by percent composition of combined data for both methods (the All category).

Species	Wadable	Nonwadable	All
Longear sunfish (*Lepomis megalotis*)	17.08	12.39	16.30
Bluntnose minnow (*Pimephales notatus*)	13.54	1.16	11.50
Common stoneroller (*Campostoma anomalum*)	8.27	0.03	6.92
Bluegill (*Lepomis macrochirus*)	4.57	12.64	5.90
Silverjaw minnow (*Ericymba buccata*)	6.48	0.00	5.41
Blackstripe topminnow (*Fundulus notatus*)	5.49	0.57	4.68
Creek chub (*Semotilus atromaculatus*)	5.44	0.03	4.55
Golden redhorse (*Moxostoma erythrurum*)	3.90	3.78	3.88
Sand shiner (*Notropis stramineus*)	4.07	0.03	3.41
Gizzard shad (*Dorosoma cepedianum*)	1.08	14.12	3.22
Spotted bass (*Micropterus punctulatus*)	2.53	3.46	2.68
Green sunfish (*Lepomis cyanellus*)	2.92	1.14	2.63
Striped shiner (*Luxilus chrysocephalus*)	2.58	0.00	2.15
Redfin shiner (*Lythrurus umbratilis*)	2.45	0.19	2.08
Common carp (*Cyprinus carpio*)	0.54	9.45	2.01
White sucker (*Catostomus commersoni*)	2.36	0.20	2.01
Suckermouth minnow (*Phenacobius mirabilis*)	1.98	0.06	1.66
Steelcolor shiner (*Cyprinella whipplei*)	1.73	0.65	1.55
Spotfin shiner (*Cyprinella spiloptera*)	1.44	1.13	1.39
Creek chubsucker (*Erimyzon oblongus*)	1.53	0.17	1.31
Freshwater drum (*Aplodinotus grunniens*)	0.06	6.21	1.07
Johnny darter (*Etheostoma nigrum*)	1.11	0.00	0.93
Pirate perch (*Aphredoderus sayanus*)	0.99	0.21	0.86
Smallmouth buffalo (*Ictiobus bubalus*)	0.01	5.04	0.84
Channel catfish (*Ictalurus punctatus*)	0.28	3.53	0.82
Quillback (*Carpiodes cyprinus*)	0.52	2.31	0.81
Yellow bullhead (*Ameiurus natalis*)	0.80	0.23	0.71
Shorthead redhorse (*Moxostoma macrolepidotum*)	.64	0.71	0.65
Northern hog sucker (*Hypentelium nigricans*)	0.74	0.00	0.62
Largemouth bass (*Micropterus salmoides*)	0.28	2.10	0.58
Spotted sucker (*Minytrema melanops*)	0.42	1.20	0.55
Orangespotted sunfish (*Lepomis humilis*)	0.23	1.90	0.51
Blackside darter (*Percina maculata*)	0.56	0.24	0.51
Orangethroat darter (*Etheostoma spectabile*)	0.60	0.00	0.50
White crappie (*Pomoxis annularis*)	0.12	1.91	0.42
Golden shiner (*Notemigonus crysoleucas*)	0.44	0.23	0.41
Flathead catfish (*Pylodictis olivaris*)	0.08	1.97	0.39
Warmouth (*Lepomis gulosus*)	0.20	1.21	0.37
Bullhead minnow (*Pimephales vigilax*)	0.30	0.67	0.36
Bigmouth buffalo (*Ictiobus cyprinellus*)	0.00	1.77	0.29
Grass pickerel (*Esox americanus vermiculatus*)	0.20	0.63	0.27
Yellow bass (*Morone mississippiensis*)	0.00	1.38	0.23
Brook silverside (*Labidesthes sicculus*)	0.19	0.37	0.22
Mimic shiner (*Notropis volucellus*)	0.13	0.49	0.19
River carpsucker (*Carpiodes carpio*)	0.00	1.11	0.18
White bass (*Morone chrysops*)	0.00	0.88	0.15
Western mosquitofish (*Gambusia affinis*)	0.15	0.09	0.14
Black crappie (*Pomoxis nigromaculatus*)	0.09	0.24	0.11
Greenside darter (*Etheostoma blennioides*)	0.11	0.03	0.10
Logperch (*Percina caprodes*)	0.11	0.00	0.09
Ribbon shiner (*Lythrurys fumeus*)	0.09	0.00	0.08
Shortnose gar (*Lepisosteus platostomus*)	0.05	0.17	0.07
Longnose gar (*Lepisosteus osseus*)	0.01	0.25	0.05
Bowfin (*Amia calva*)	0.02	0.20	0.05
Black bullhead (*Ameiurus melas*)	0.02	0.20	0.05

Table 1. *Continued.*

Species	Wadable	Nonwadable	All
Tadpole madtom (*Notorus gyrinus*)	0.03	0.06	0.04
Slenderhead darter (*Percina phoxocephala*)	0.05	0.00	0.04
Redear sunfish (*Lepomis microlophus*)	0.00	0.20	0.03
Silver chub (*Macrhybopsis storeriana*)	0.00	0.13	0.02
Emerald shiner (*Notropis atherinoides*)	0.00	0.09	0.02
Mississippi silvery minnow (*Hybognathus nuchalis*)	0.01	0.06	0.02
Brindled madtom (*Noturus miurus*)	0.02	0.00	0.02
Striped bass (*Morone saxatilis*)	0.00	0.10	0.02
Black buffalo (*Ictiobus niger*)	0.00	0.06	0.01
Highfin carpsucker (*Carpiodes velifer*)	0.00	0.05	0.01
Blue catfish (*Ictalurus furcatus*)	0.00	0.08	0.01
Freckled madtom (*Noturus nocturnus*)	0.01	0.03	0.01
Spotted sunfish (*Lepomis punctatus*)	0.00	0.03	0.01
Sauger (*Stizostedion canadense*)	0.00	0.07	0.01
Walleye (*Stizostedion vitreum*)	0.00	0.06	0.01
Mud darter (*Etheostoma asprigene*)	0.01	0.03	0.01
American eel (*Anguilla rostrata*)	0.00	0.03	0.00
Hybrid sunfish (*Lepomis* spp.)	0.30	0.26	0.29

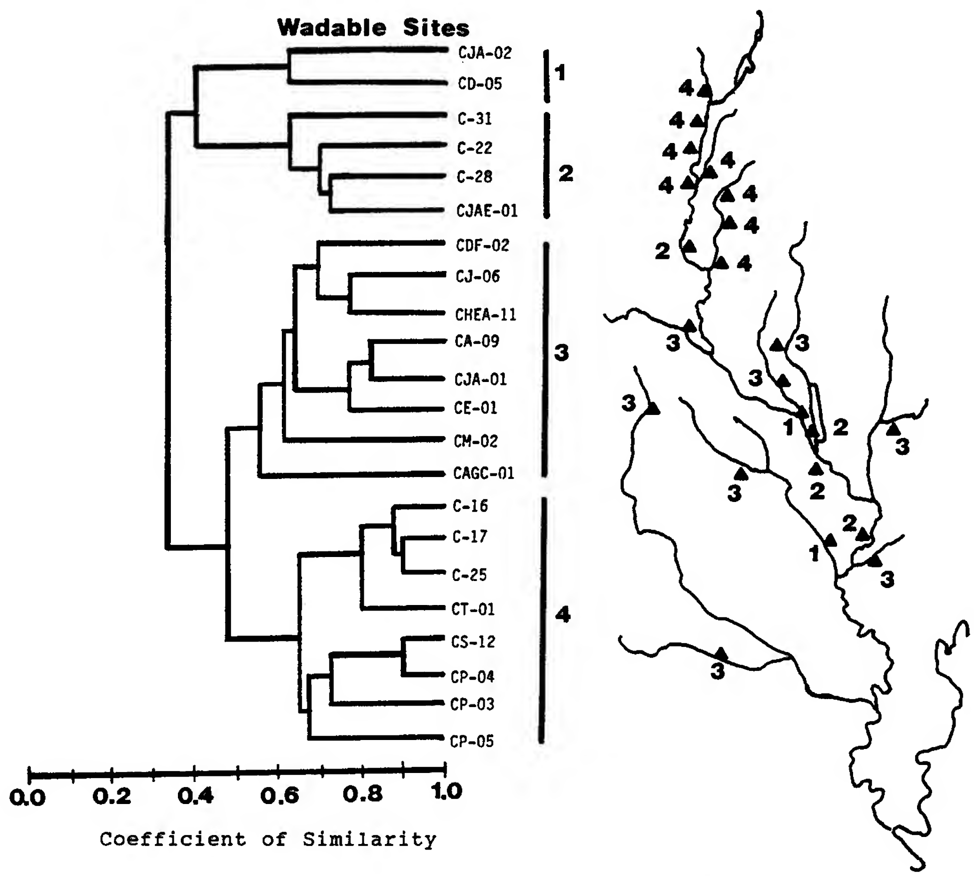

Fig. 3. For wadable (electric seine) sites, a dendrogram was developed using Horn's Index of Community Similarity and an unweighted multiple pair-group analysis. Values are based on number per hour of fish collected. Distribution of stations within each community group (1–4) is displayed on the adjacent map.

Table 2. Dominant species from nonwadable (boat) and wadable (electric seine) sites in major community groups.

Nonwadable sites[a]		Wadable sites[b]	
Group	Species	Group	Species
1	Channel catfish, flathead catfish, freshwater drum, white crappie	1	Gizzard shad, common carp, bullhead minnow black crappie, orangespotted sunfish, warmouth, blackside darter, freshwater drum
2	Bigmouth buffalo, longear sunfish largemouth bass, yellow bullhead	2	Gizzard shad, bluntnose minnow, bullhead minnow channel catfish, longear sunfish, spotted bass steelcolor shiner, suckermouth minnow, hybrid sunfish
3	Bigmouth buffalo, longear sunfish spotted bass	3	Suckermouth minnow, bluntnowe minnow, creek chubsucker, blackstripe topminnow, longear sunfish. pirate perch, yellow bullhead
4	Channel catfish, flathead catfish longear sunfish, river carpsucker freshwater drum	4	Suckermouth minnow, creek chub, redfin shiner, sand shiner, spotfin shiner, striped shiner bluntnose minnow, common stoneroller, silverjaw minnow, blackstripe topminnow, white sucker, longear sunfish, spotted bass, johnny darter

[a]Common species: common carp, smallmouth buffalo, bluegill, gizzard shad.
[b]Common species: bluegill, green sunfish.

Wadable Group 4 stations were on the mainstem and tributaries in the upper portion of the Little Wabash River watershed (Fig. 3). In comparison with other groups, Group 4 had the lowest abundance of bluegill and largemouth bass, but the highest relative abundance of spotted bass. The conservative Tukey's test was unable to detect between which groups significant differences were present, but through the ANOVA, significant differences were observed between groups for bluegill and spotted bass (Table 3).

Nonwadable Sites

At nonwadable sites four major community groups were also delineated, but the presence or relative abundance of a species or species-complex characterizing a particular group was not as distinct as observed at wadable sites (Fig. 4). Several species, including common carp, bluegill, gizzard shad, and smallmouth buffalo, were considered common among all groups (Table 2). Stations from Groups 1 and 4, located primarily in the middle and lower mainstem, along with the two lower stations on Skillet Fork, held flathead catfish, freshwater drum, and channel catfish. White crappie were common to Group 1 communities, while longear sunfish were typical of Group 4 communities. River carpsucker were likewise characteristic of Group 4. In addition to their occurrence in Group 4, longear sunfish were also typical of Groups 2 and 3. In comparison with Groups 1 and 4, Groups 2 and 3 differed in spatial distribution and fish composition. These stations were mostly in tributaries and many middle or upper mainstem stations. Bigmouth buffalo were common in Groups 2 and 3. The apparent differences between Groups 2 and 3 were Group 2 holding largemouth bass, while Group 3 contained spotted bass (Table 3).

Only bluegill and channel catfish relative abundances were significantly different among groups (Table 3). Group 2 sites, on the Fox River and Big Muddy Creek, held more bluegill than either Group 1 or Group 3. One of these Group 2 sites (CH-03) was located above the dam at Olney and thus represented a lentic reach. Channel catfish in Groups 1 and 4, located primarily in the middle and lower mainstem, were more abundant than at Group 2. Channel catfish from Group 1 were also more abundant than at Group 3 (upper mainstem).

Index of Biotic Integrity

At wadable sites, IBI values ranged from 29.4 to 51.3 (Fig. 5). Notably, samples from the upper portion of the watershed had higher values than those from other parts of the watershed. Mean IBI values from stations contained within community Group 4 of the wadable sites were significantly

($P \leq 0.05$) higher than those of Group 1 or 3 (Table 3).

At nonwadable sites IBI values ranged from 29.4 to 44.7 (Fig. 5). Again, the higher values were found in the upper part of the mainstem and in upper Skillet Fork. An exception to this relationship was observed at C-18, located downstream of Lake Paradise, in an area impounded by a brush-debris jam. No significant difference ($P > 0.05$) was observed in mean IBI values between community groups at nonwadable sites.

Only four tributaries, including West Branch, had at least one site with an IBI of 40 or greater. Only two tributaries, Salt Creek (41.1) and Little Muddy Creek (40.4), had multiple sites with mean values exceeding 40. On upper Skillet Fork, IBI scores at two nonchannelized, nonheadwater sites of 44.7 (CA-07) and 40.4 (CA-08) were notably higher than the 31.6 of the downstream channelized section.

The comparison of IBI values from locations sampled in 1976 (Fisher and Lockart, IDOC, Aledo, Illinois, unpublished data) and 1989 showed no significant difference ($t = 1.200$, $P \geq 0.05$, 10 df) between years. Of these 11 mainstem stations, only the farthest upstream site had an IBI value greater than 40.

Habitat and Discharge

Wadable Sites

At wadable sites, substrate composition on the upper mainstem and tributaries (Green Creek, Salt Creek) was dominated by sand and gravel (Fig. 6). At only three other wadable sites (CJ-06, CJAE-01, CD-05) did sand and gravel account for over 50% of the substrate (Fig. 7). Claypan or silt was the dominant substrate type at most other sites. Bedrock was abundant only at CHEA-01, where it accounted for about one-third of the substrate. Hydrologically, most sites were characterized as pool and run.

Based on the community grouping, Group 4 (upper watershed) had significantly more sand than either Group 1 or 3 (Table 3). Group 1 stations had more plant detritus than any other group. For other substrate types, significant differences were also observed in silt, clay, and submerged logs, but we were unable to detect specific differences between groups.

Nonwadable Sites

At nonwadable tributary sites, estimates of substrate composition indicated that tributary stations were dominated by silt and clay, with occasional occurrence of sand and gravel (Fig. 8). Substrate at nonwadable mainstem sites was variable and often contained more sand and gravel than the tributaries (Fig. 9). At only two sites was bedrock abundant, accounting for 20% (C-13) and 85% (C-01) of the substrate. As observed at wadable sites, pools and runs were hydrologically characteristic features, with only C-01 dominated by riffles.

Only shading was significantly different among groups, with Group 2 having significantly more shade than either Group 1 or 3 (Table 3).

The strongest seasonal pattern in discharge was observed at the farthest downstream station at Carmi (Fig. 10). Two high-flow periods were seen, the first in December and January, followed by a prolonged period from March to early July. This second period showed a steady decline from its peak in April. Accompanying the higher discharge from upstream to downstream was a greater stability in flow, as indicated by the decreasing coefficient of variability.

No consistent seasonal pattern was observed in turbidity among the three mainstem stations. Overall, however, mean turbidity increased from upstream to downstream (Fig. 11).

Water Quality

According to Hite et al. (1992), water quality, as indicated by WQI, revealed most stations with only minor problems (values between 20 and 50). Stations C-16, C-17, CT-01, C-07, C-12, and C-18 in the middle and upper mainstem seemed least degraded, with values less than 20. Upper mainstem water quality was very good to excellent, while middle and downstream portions were of moderate quality. The decline in water quality in the middle and downstream reaches was attributed to two sources: total phosphorus and suspended solids (Hite et al. 1992). On tributaries, most notably, in contrast to other sites in the upper watershed, high WQI values (62.6–68.4) were recorded on Salt Creek at CP-03 and CP-05. Taking into account all stations, these values were exceeded only at CH-11 (WQI 75.3).

Using community grouping of stations, no significant differences were found among groups for any water quality variable at wadable sites (Table 3). At nonwadable sites, a significantly ($P \leq 0.05$)

Table 3. Mean values of habitat and fish variables, evaluated by community groups. Percent values have been square root arcsine transformed. Fish relative abundances and species richness have been log (x+1) transformed.

Nonwadable sites

Habitat variable	Community group 1[a]	2	3	4[b]	ANOVA P =
n =	8	3	9	5	
Silt (%)	44.6	59.7	45.7	36.3	0.596
Sand (%)	21.5	0.0	23.1	26.8	—[d]
Gravel (%)	9.2	0.0	4.9	10.9	—[d]
Cobble (%)	4.2	0.0	0.0	0.0	—[d]
Boulder (%)	2.6	0.0	0.0	0.0	—[d]
Bedrock (%)	12.7	0.0	0.0	2.6	—[d]
Clay (%)	6.6	13.1	17.5	18.6	0.593
Detritus (%)	4.8	6.1	9.0	14.2	0.299
Other (%)	7.7	11.1	4.4	6.3	0.828
Pool (%)	26.6	85.7	57.7	48.7	0.130
Run (%)	49.0	0.0	28.0	41.3	—[d]
Riffle (%)	15.8	4.3	4.3	0.0	—[d]
Shading (%)	28.9	75.0	61.1	24.0	0.005
Submergent veg. (%)	0.0	0.0	0.0	0.0	—[d]
Emergent veg. (%)	0.0	0.3	0.2	0.0	—[d]
Floating veg. (%)	0.4	0.7	0.7	0.4	0.617
Mean water width (ft.)	88.8	46.7	68.1	92.0	0.205
Mean depth (ft.)	3.1	2.2	3.2	2.8	0.336
Index of biotic integrity (IBI)	32.6	35.6	37.7	33.2	0.067
No. of species[e]	1.2	1.3	1.3	1.3	0.460
Bluegill/h	0.8	1.8	0.9	1.2	0.006
Common carp/h	1.2	1.0	1.0	1.1	0.598
Channel catfish/h	1.0	0.1	0.2	0.6	0.000
Largemouth bass/h	0.2	0.8	0.4	0.5	0.072
Spotted bass/h	0.3	0.6	0.8	0.4	0.135
Number darter species	0.1	0.0	0.1	0.1	—[d]
Number sunfish species[e]	0.7	0.9	0.8	0.8	0.123
Water temp. (° C)	26.0	24.7	24.7	28.0	0.121
Turbidity (NTU's)	33.0	15.3	16.0	16.4	0.515

Wadable sites

Habitat variable	Community group 1	2[c]	3	4	ANOVA P =
n =	2	4	8	8	
Silt (%)	38.4	17.0	28.2	9.4	0.028
Sand (%)	32.6	51.0	23.0	57.1	0.002
Fine gravel (%)	12.0	14.4	15.0	24.3	0.104
Medium gravel (%)	5.3	12.8	9.0	8.3	0.788
Coarse gravel (%)	2.2	5.2	2.2	2.4	0.646
Small cobble (%)	0.0	8.4	1.2	1.9	—[d]
Large cobble (%)	0.0	7.4	1.4	0.0	—[d]
Boulder (%)	0.0	1.8	3.4	4.5	—[d]
Bedrock (%)	0.0	1.8	4.4	0.0	—[d]
Clay (%)	5.3	8.9	25.4	3.5	0.039
Plant detritus (%)	16.2	2.6	6.6	1.5	0.045
Vegetation (%)	0.0	4.8	9.8	0.7	—[d]
Submerged logs (%)	12.8	5.3	10.9	2.5	0.038
Other (%)	0.0	0.0	1.0	0.0	—[d]
Pool (%)	43.1	32.6	61.9	45.6	0.064
Riffle (%)	2.6	11.9	1.6	9.4	0.077
Run (%)	46.6	52.9	27.9	41.8	0.103
Shading (%)	31.8	41.8	36.0	39.9	0.785
Instream cover (%)	13.9	8.2	14.5	11.4	0.015
Discharge (cfs)	3.2	14.0	0.7	2.0	0.027
Mean velocity (ft/s)	0.2	0.3	0.1	0.2	0.198
Mean water width (ft)	28.4	47.1	20.0	21.0	0.001
Mean depth (ft)	1.1	0.8	0.8	0.7	0.475
Index of biotic integrity (IBI)	38.2	37.1	34.4	44.2	0.001
No. of species[b]	1.4	1.3	1.3	1.4	0.168
Bluegill/h	1.6	1.0	1.6	0.7	0.027
Common carp/h	1.1	0.5	0.3	0.4	0.353
Channel catfish/h	0.4	0.8	0.1	0.2	0.004
Largemouth bass/h	0.5	0.2	0.6	0.0	—[d]
Spotted bass/h	0.5	1.1	0.2	1.2	0.016
Number darter species	0.4	0.4	0.3	0.5	0.361
Number sunfish species	0.9	0.8	0.8	0.7	0.114
Water temp. (° C)	26.8	24.6	24.0	24.7	0.766
Turbidity (NTU's)	31.0	26.5	16.1	10.4	0.341

Table 3. *Continued.*

Nonwadable sites					
Habitat variable	Community group 1[a]	2	3	4[b]	ANOVA P =
Conductivity (µmhos)	479.3	470.0	482.6	451.2	0.982
D.O. (mg/L)	7.0	4.2	5.5	8.3	0.236
Unionized NH_3-N	0.003	0.002	0.001	0.007	0.135
Total NO_2-NO_3	0.142	0.100	0.185	0.513	—[d]
Water quality index (WQI)	34.5	55.6	30.3	31.0	0.031

Wadable sites					
Habitat variable	Community group 1	2[c]	3	4	ANOVA P =
Conductivity (µmhos)	460.0	456.2	534.4	611.9	0.655
D.O. (mg/L)	4.5	5.6	6.8	5.8	—[d]
Unionized NH_3-N	0.002	0.001	0.008	0.003	0.429
Total NO_2-NO_3	0.180	0.575	0.198	1.525	0.505
Water quality index (WQI)	42.2	33.7	29.2	30.8	0.811

[a] Water quality for C-30 not available.
[b] Water quality for C-02 not available.
[c] Substrate and flow data from C-22 not available.
[d] One or more groups has no variance.
[e] Includes hybrid sunfish.

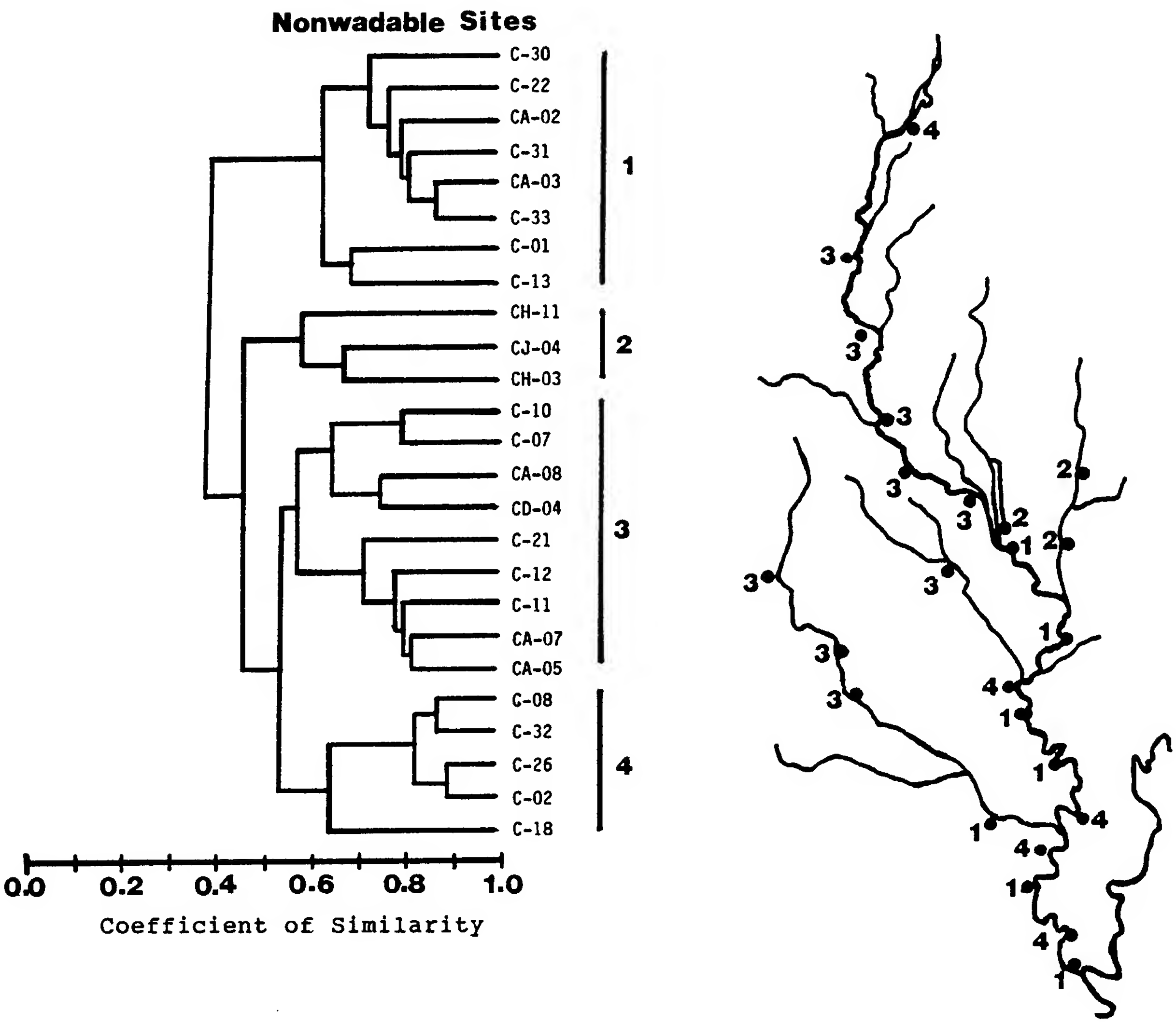

Fig. 4. For nonwadable (boat electrofishing) sites, a dendrogram was developed using Horn's Index of Community Similarity and an unweighted multiple pair-group analysis. Values are based on number per hour of fish collected. Distribution of stations within each community group (1–4) is displayed on the adjacent map.

higher WQI was found in Group 2 compared with either Group 1 or 3, indicating lower water quality at these sites (Table 3). No significant difference in WQI was found between Group 2 and 4.

Sport Fish

On the mainstem, longitudinal distribution of spotted bass and channel catfish was evident; spotted bass were found primarily in the upper portion of the river and channel catfish in the middle reaches (Table 4). However, in lower reaches, especially at the two farthest downstream stations (C-01, C-26), both species were collected. The large number of spotted bass less than stock length (L) at C-21 and C-28 indicates use of these sites for nursery or spawning purposes.

Compared with spotted bass and channel catfish, other sport species, such as white crappie, common carp, and bluegill, were more generally distributed throughout the mainstem. Largemouth bass were not collected consistently and were usually low in relative abundance (Table 4). Largemouth bass of preferred size were collected at the uppermost mainstem station (C-18), located immediately downstream of Lake Mattoon, and are thus thought to have originated from this lake.

In tributaries, bluegill of stock length were abundant on the Fox River (CH-03) and Big Muddy Creek (CJ-04; Table 4), while large numbers of bluegill less than stock length were collected in

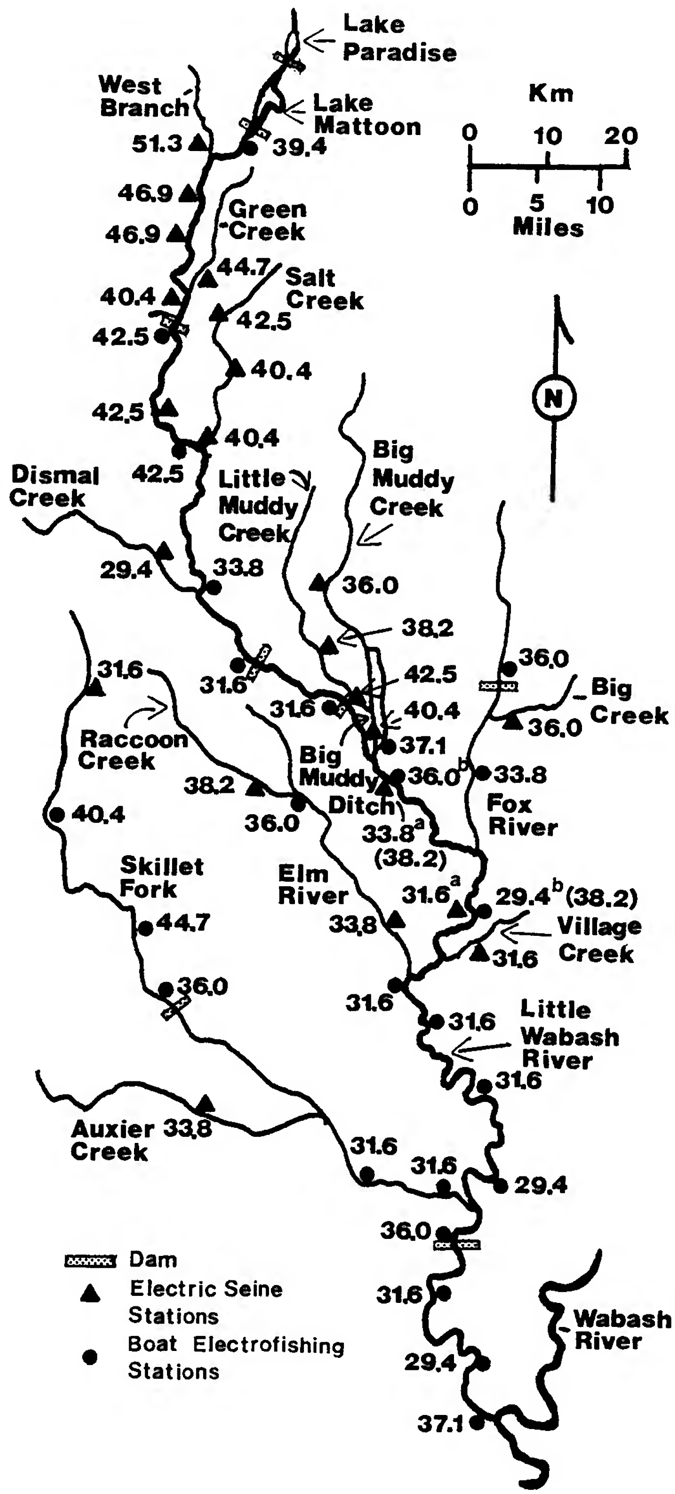

Fig. 5. Map of the Little Wabash River watershed showing Index of Biotic Integrity (IBI) values. For stations C-22 and C-31, values are by method (e.g., boat electrofishing and seine hauls[a] or electric seine[b]) followed by the score for all methods combined (in parentheses).

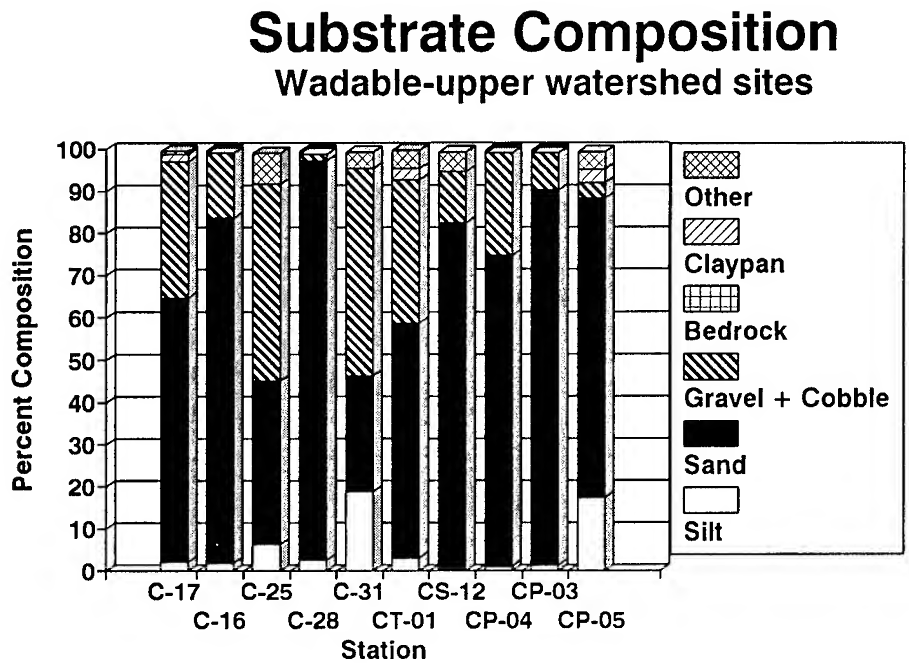

Fig. 6. Substrate composition from wadable (electric seine) sites in the upper watershed.

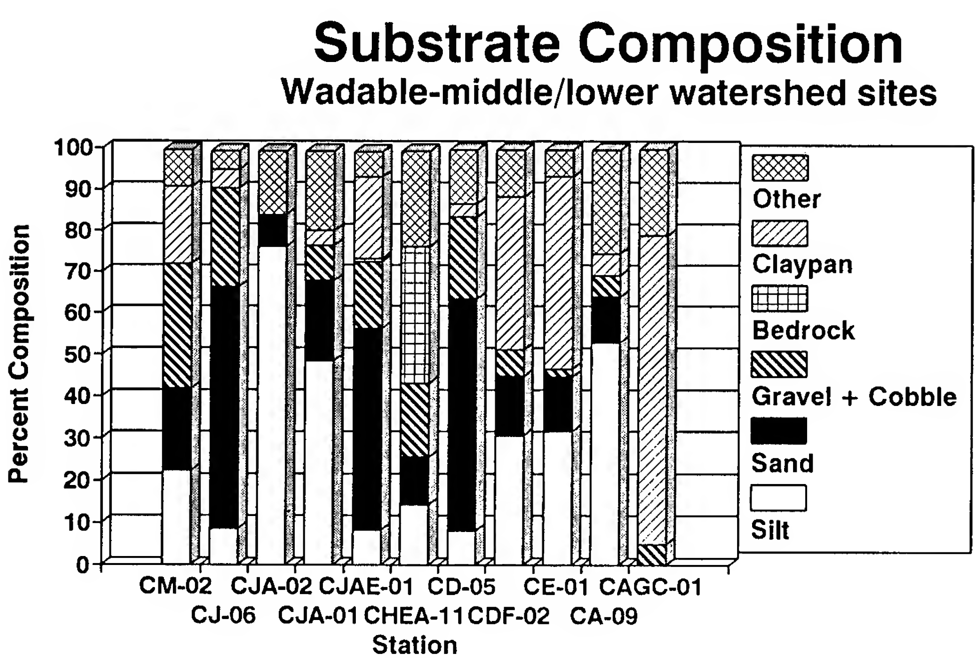

Fig. 7. Substrate composition from wadable (electric seine) sites in the middle and lower watershed.

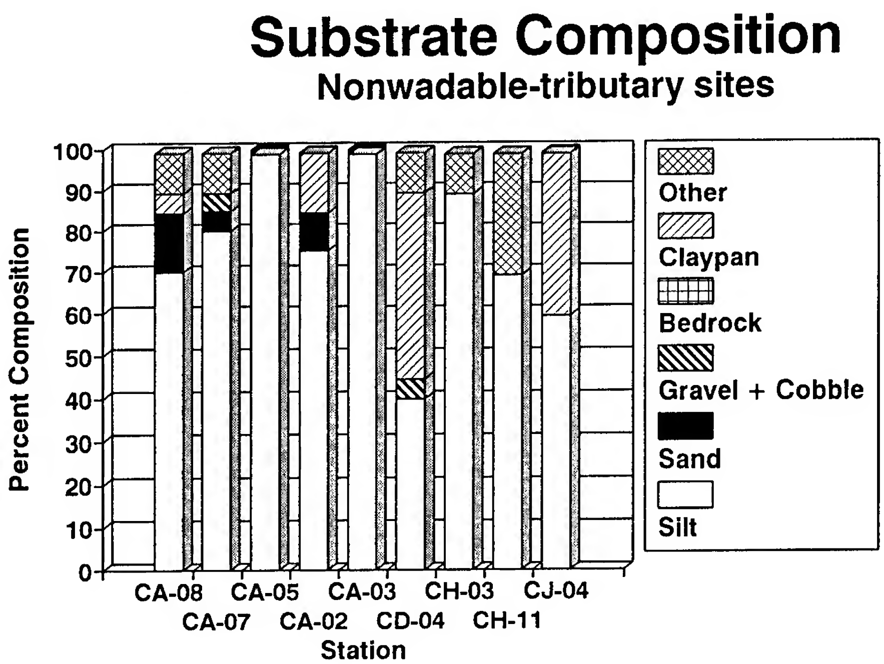

Fig. 8. Substrate composition from nonwadable (boat electrofishing) tributary sites.

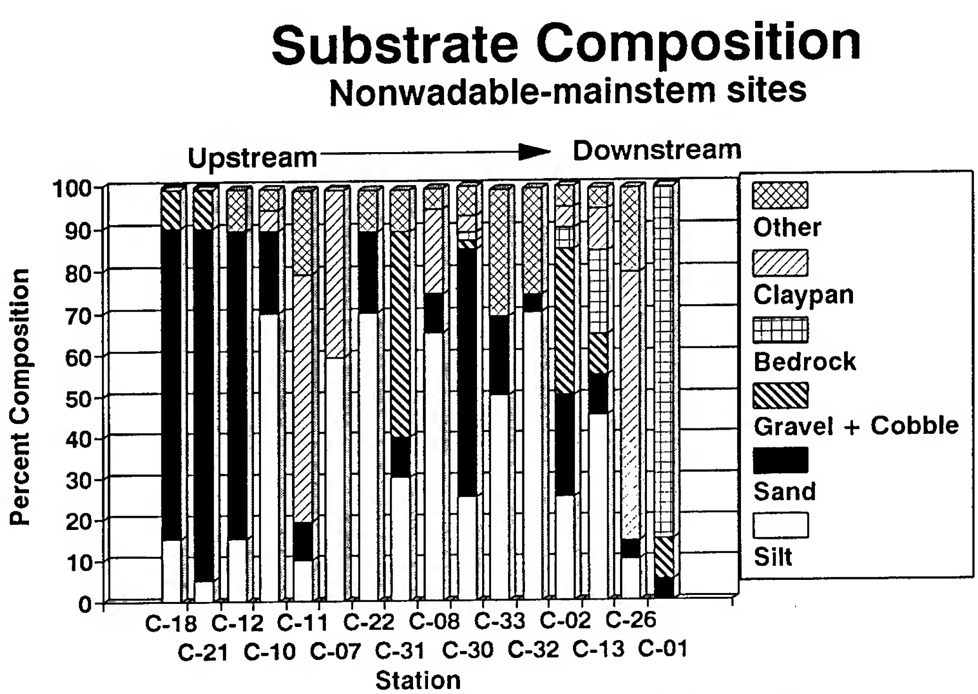

Fig. 9. Substrate composition from nonwadable (boat electrofishing) mainstem sites.

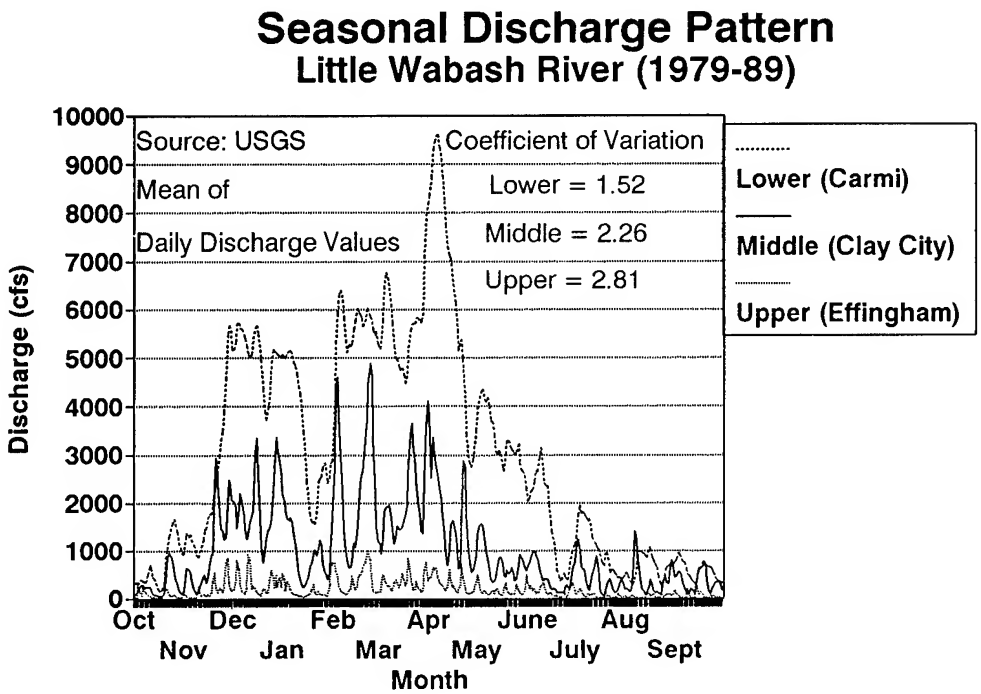

Fig. 10. Seasonal discharge pattern of the Little Wabash River as reported by the U.S. Geological Survey. Values are based on mean of daily discharge for each day of the year, for 1979–89 beginning 1 October 1979. Coefficient of variation is calculated using all daily values for the entire period for each location.

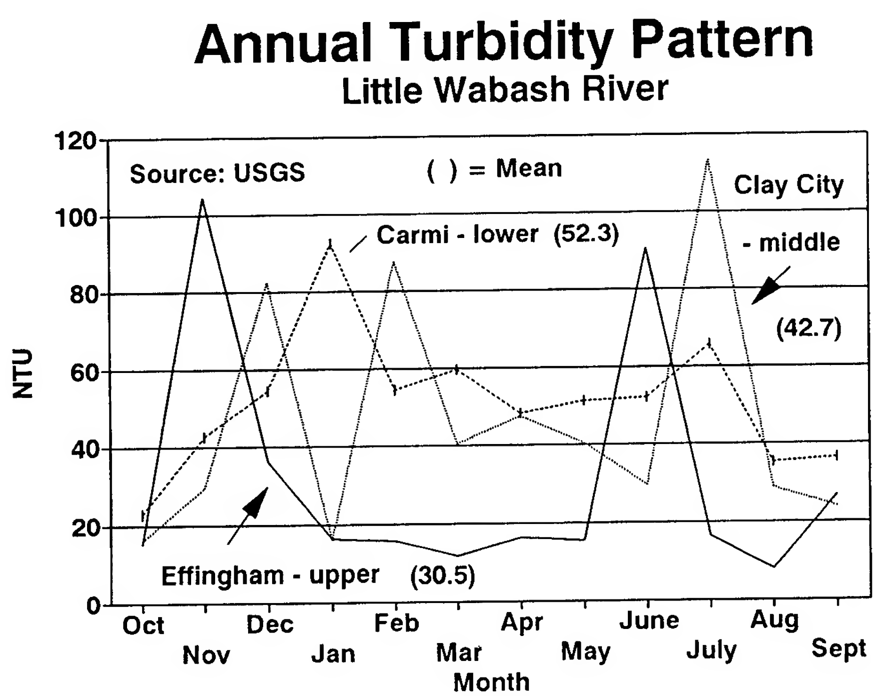

Fig. 11. Annual turbidity (NTU's) pattern of the Little Wabash River as reported by the U.S. Geological Survey. Values are averages for each month for 1979–89. Note: Samples were not taken each month.

Table 4. Size categorization[a] of sport fish collected in the Little Wabash River basin (L = less than stock; S = stock; Q = quality; P = preferred; M = memorable). Values are total numbers of fish collected using all sampling methods (i.e., boat electrofishing, electric seine, and seine hauls).

Site from upstream to down-stream)	Spotted bass				Channel catfish				Largemouth bass				White crappie					Common carp					Bluegill			
	L	S	Q	P	L	S	Q	P	L	S	Q	P	L	S	Q	P	M	L	S	Q	P	M	L	S	Q	P
Little Wabash River																										
C18		2							1	5	3	3		7					10	3			2	6	4	
C17	14	12	1		1														1	2				2		
C16	7	4	1		2									1						2	1		5			
C25	7	5	1																1	3			19			
C21	36	3							2	1	1		2						2	1	1		11			
C28	30	9			1				5				1										22	2		
C12[b]	4	1							4				1						2	3			6	4	1	
C10	3					3	3								1				1	5	1	1	9	4		
C11	11	7			1				1					2	2	1			1	6	1		5	2		
C07	3	1				1							1	2	2	1			3	11	1		2	4		
C22	7	2			4	4	1							1	1				8	17	2		1	1		
C31	1			13	2								2	1	1				5	13			3	7	2	
C08				1	1									2	2				2	13	2		1	6	1	
C30				9	10	7										1			5	13	1					
C33				3	3			2	1				4	1	1				1	9	1		2	5	5	
C32				2	2	1									1			1	2	8	4		1	11	6	
C0	2	2				2	3			4				1	1	1				3	1		18	15	6	
C13	1	1			5	2	8						2	1						4	3			4	2	
C26	4	2	1		2		2		1	2			1			1					5	2	3	11	6	
C01	5	1	3	1	21	3	2			1					1					5	1	5	13	4		
Skillet Fork (All stations)																										
	8	2			5	3	3		3	3	1		2	8	3	1	1	1	21	41	6		28	18	2	
Auxier Creek																										
CAGC-01			2					4															109	4		
Elm River (All stations)																										
	1			2					2	1								3	8	2			27	3		
Raccoon Creek																										
CDF02								2	1	1			2										5	2		
Village Creek																										
CE01																		12	3	5	2		9	15		
Fox River (All stations)																										
	1						1		1	3	7	3		1	3				8	8			17	68	1	

Table 4. *Continued.*

Site from upstream to down-stream)	Spotted bass				Channel catfish				Largemouth bass				White crappie					Common carp					Bluegill			
	L	S	Q	P	L	S	Q	P	L	S	Q	P	L	S	Q	P	M	L	S	Q	P	M	L	S	Q	P
Big Creek																										
CHEA-11		9								3	1												83	16	1	
Big Muddy Creek (All stations)		29								2	2	1	11	9							5	1	68	49	2	
Little Muddy Creek (All stations)	3	1	1							3			1	3	1			1	1	4	1		28	17	1	
Big Muddy Ditch																										
CJAE-01		13	2			2																	4	3		
Dismal Creek																										
CM02																										
Salt Creek (All stations)		3		1															1	1			5	1		
Green Creek																										
CS-12	22																									
West Branch																										
CT-01	54	2																						2		

[a]Minimum length (mm) for size categories (Gabelhouse 1984).

	L (Less than Stock)	S (Stock)	Q (Quality)	P (Preferred)	M (Memorable)
Spotted bass	< 180	180	280	350	430
Largemouth bass	< 200	200	300	380	510
Channel catfish	< 280	280	410	610	710
White crappie	< 130	130	200	250	300
Common carp	< 280	280	410	530	660
Bluegill	< 80	80	150	200	250

[b]Includes fish from only first 30 min of sampling effort.

Auxier Creek (CAGC-01), Big Creek (CHEA-11), and Big Muddy Creek (CJ-04; Table 4). Spotted bass less than stock length were numerous at CS-12 and CT-01 (Table 4), in the upper portion of the watershed. As with upper mainstem stations C-21 and C-28, the presence of a large number of young-of-the-year and yearling spotted bass indicates the importance of these areas for recruitment.

Largemouth bass, white crappie, and common carp were distributed throughout the tributaries, but typically were not found in tributaries of the upper portion of the watershed (Salt Creek, Green Creek, West Branch).

Discussion

Basinwide fish species richness (74) was about one-third of the 202 species known to occur in Illinois (Burr et al. 1988). Our total count approached the 78 species reported by Smith (1971), though we were unable to compare species composition because Smith (1971) did not provide a species list. Our results agree with those of Smith (1971), indicating higher quality stations in the upper watershed. From our sampling, the upper mainstem (with the exception of C-18) and adjacent tributaries, according to IBI, were among the highest rated in the watershed. Only four remaining stations in other subbasins (CA-07, CA-08, CJA-02, CJAE-01) had IBI values exceeding 40.

At wadable sites, many of the differences in community groups seemed to be based on substrate. For example, several species found in Group 4 communities were typically silt intolerant (spotted bass, northern hogsucker; Hite and Bertrand 1989) or required coarser substrates (greenside darter, blackside darter, common stoneroller; Smith 1979). Sand and fine gravel were abundant at these sites. The presence of these substrates in the upper watershed appeared strongly associated with the Shelbyville Moraine and the coarse material often found with such geologic features (Barker et al. 1967). Stream gradient was also higher in the upper portion of the watershed (Barker et al. 1967). Substrate and current velocity were noted by Gorman and Karr (1978) as important features in habitat specialization by fish. Though sand and fine gravel also occurred at other wadable sites, silt and clay were higher in abundance and thus probably contributed to the distinction between the groups.

At nonwadable sites, many species were common to all community groups, with only one or two species different between groups. At these sites few significant associations among habitat variables were observed, which may be attributable to the considerable habitat heterogeneity, exhibited by the lack of a dominant feature (e.g., substrate type), as observed in Group 4 of the nonwadable sites. Gorman and Karr (1978) noted horizontal heterogeneity as a feature strongly influencing fish community structure.

The distribution of two sport fish, spotted bass and channel catfish, appeared associated with several habitat features. According to Smith (1979) and Burr and Warren (1986), spotted bass are found in areas of sand and gravel substrates with low to moderate flows. These features were typical of the upper mainstem. The lower overall turbidity in the upper reaches may enhance feeding efficiency for such predators. Spotted bass are also found in larger rivers and reservoirs, with potential movement between larger rivers and tributaries (Pflieger 1975).

Channel catfish occur in diverse habitats (see McMahon and Terrell 1982 for a review of channel catfish ecology). In rivers, adults use pool habitats with cover during the day and move to riffle and run habitats to feed at night (Pflieger 1975). Though found in the upper portion of the Little Wabash River, these habitat characteristics, especially greater depth, were more often present in the middle and lower mainstem, where pools were occasionally interspersed with riffles (C-22, C-31) or runs (C-30, C-13, C-33). This was evident at the deeper wadable sites (Community Group 2), where channel catfish relative abundance was significantly greater ($P \leq 0.05$) than at the other three groups.

Bluegill (Pflieger 1975; see Stuber et al. 1982 for a review of bluegill ecology), as well as other sunfishes such as longear sunfish (Pflieger 1975), are most often found in areas of low current velocity. At wadable sites, pool habitat, vegetation, and narrow water width in Group 3 stations were typical features of these stream reaches (Table 3) and were dominated by species characteristic of these conditions.

As a major habitat component affecting fish and other aquatic biota, discharge variability can affect fish community composition (Horwitz 1978; Poff and Ward 1989). Similar to the results of Horwitz (1978), discharge variation on the Little Wabash River, based on the coefficient of variation, in-

creased from downstream to upstream. Horowitz found increasing species richness with decreasing variability of flow. Using only samples from nonwadable mainstem sites, we found a similar trend, with a higher species richness at the four farthest downstream sites (mean 24.5, range 22–28) compared with the four farthest upstream sites (mean 19.5, range 16–22). Modest decline in species richness at middle stations (C-08, C-30, C-33, C-32; mean 14.3) supports the contention by Hite et al. (1992) of a possible water quality problem. The lower quality of this middle section of the mainstem did not appear attributable to destruction of the riparian zone, which remains mostly forested (ISIS, Springfield, Illinois, unpublished data). Rather, cumulative effects from modified tributaries, as well as point source pollution (i.e., oil wells, waste-water treatment facilities), probably contribute to the decline in quality of the mainstem. In this watershed "oil-field pollution, siltation, and dessication during drought" have been noted as negative effects on the fish community (Smith 1971).

In addition to human-induced degradation, soils of this watershed may influence stream quality. Many of the soils in the basin are developed primarily from loess and are subject to erosion. Consequently, suspended sediment composed of clay and silt (particles <0.062 mm) can be substantial, especially during high discharge periods (Zeuhls 1987). Even in the early 1900's Forbes and Richardson (1920) noted the presence of clay soils in this region and their effects on water clarity. Based on U.S. Geological Survey data, a general longitudinal increase in turbidity occurs on the Little Wabash River.

The influence of habitat modification on the fish resource was readily seen in the Skillet Fork drainage. The loss of instream and riparian cover in the lower reaches because of channelization was reflected in the lower IBI values (mean 33.1) of this degraded reach compared with the nonchannelized, nonheadwater segment of upper Skillet Fork (mean IBI of 42.5).

Because of the potential cumulative influence of watersheds similar to the Little Wabash River on the Mississippi River, protection and restoration initiatives require a multidisciplinary (i.e., fisheries, botanists, agronomists, geologists) as well as a multijurisdictional (i.e., local, state, federal, and private agencies) approach. The spatial and temporal perspectives contained within the "physical-habitat template" developed by Poff and Ward (1990) could guide establishment of recovery criteria and management objectives.

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Fishes of the Big Muddy River Drainage With Emphasis on Historical Changes

by

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Abstract. The Big Muddy River, a lowland stream located in southwestern Illinois and draining an area of about 6,182 km^2, contains a moderately diverse fish fauna of 106 species. The river is properly named, as the mainstem carried historically and continues to transport great quantities of silt. Historically, a large portion of the watershed was wooded, but much of the land has been cleared and put under cultivation. This has exacerbated siltation and eliminated former wetlands adjacent to and communicating with the mainstem and tributaries. Most of the drainage suffers from excessive siltation; dessication during drought periods; and oil-field, sewage effluent, strip-mine, and other industrial pollution. The construction of Crab Orchard, Little Grassy, Devil's Kitchen, Kincaid, Cedar, and Rend lakes effectively eliminated some of the highest quality streams in the drainage. One detrimental effect of these various stresses has been the disappearance of at least 10 native fish species over the past 100 years, including some of sport or commercial value (e.g., blue sucker, burbot). Suggested solutions to these problems include (1) a community ecology approach to future management of the drainage itself and the human made lakes; (2) maintenance or re-establishment of wooded riparian corridors, as well as wetlands adjacent to the river and tributaries, as spawning and nursery sites; (3) continued vigorous reclamation of abandoned mine lands and treatment of acid mine drainage; and (4) discontinuance of stocking of nonnative fishes (e.g., grass carp, bighead carp, striped bass, inland silverside) until their impact can be assessed.

Similar to most big river drainages in the largely agricultural state of Illinois, the Big Muddy River drainage, situated in the southwestern portion of the state (Fig. 1), has been subjected to an array of environmental stresses that have permanently disrupted its hydrological cycle, and ultimately altered its fish fauna. A century ago, the first fish collections were made in the Big Muddy River (Forbes and Richardson 1908), at about the time that the bottomland forests were beginning to be cleared for cultivation. In subsequent years, much of the well-drained, tillable ground was cleared, followed by

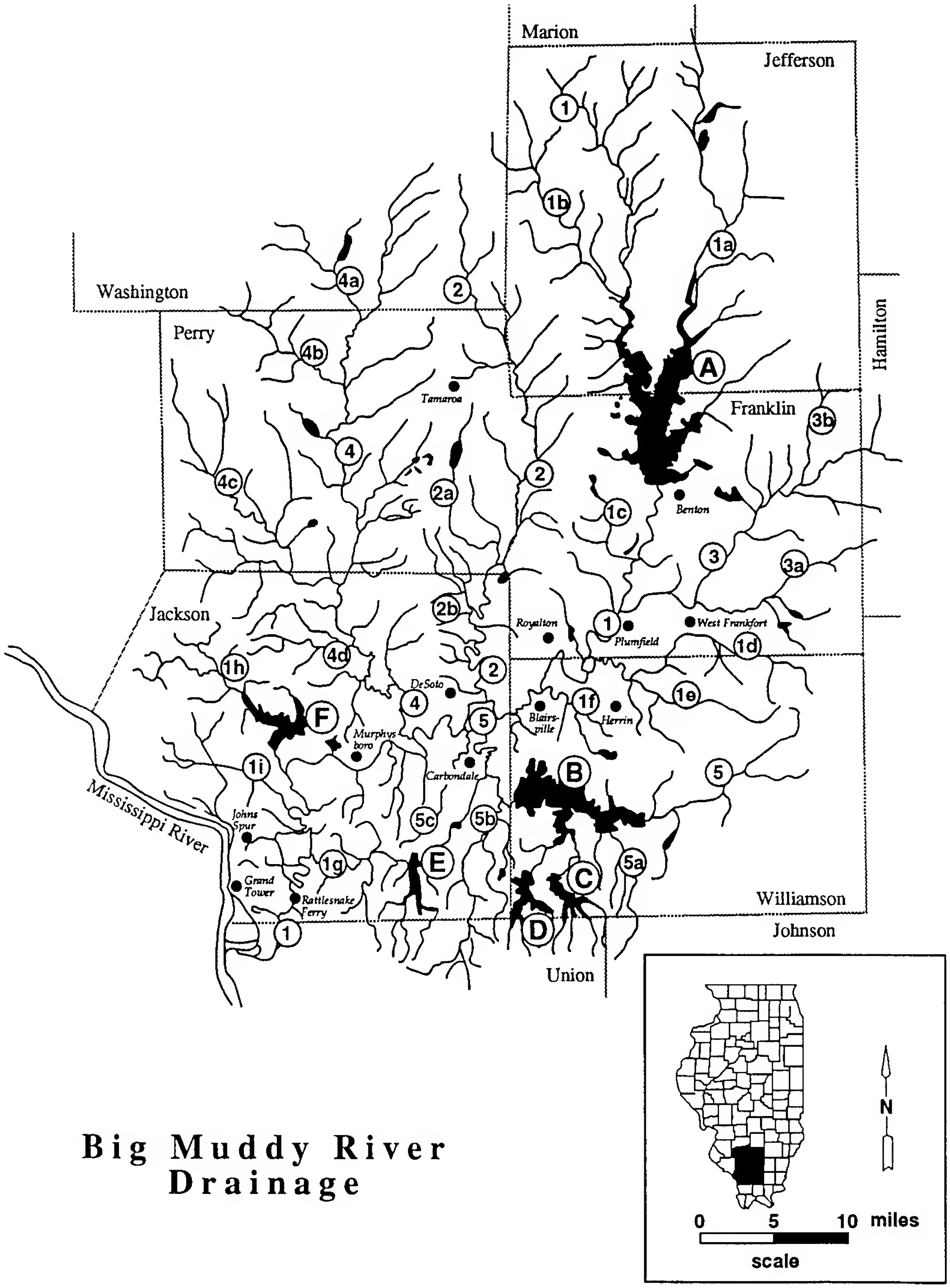

Fig. 1. Stream names, cities, counties, and reservoirs of the Big Muddy River drainage. A, Rend Lake; B, Crab Orchard Lake; C, Devil's Kitchen Lake; D, Little Grassy Lake; E, Cedar Lake; F, Kincaid Lake. 1, Big Muddy River; 1a, Casey Fork; 1b, Rayse Creek; 1c, Prairie Creek; 1d, Pond Creek; 1e, Long Creek; 1f, Hurricane Creek; 1g, Cedar Creek; 1h, Kincaid Creek; 1i, Worthen Bayou. 2, Little Muddy River; 2a, Reese C reek; 2b, Six Mile Creek. 3, Middle Fork Big Muddy River; 3a, Ewing Creek; 3b, Sugar Camp Creek. 4, Beaucoup Creek; 4a, Locust Creek; 4b, Swanwick Creek; 4c, Galum Creek; 4d, Rattlesnake Creek. 5, Crab Orchard Creek; 5a, Wolf Creek; 5b, Drury Creek; 5c, Little Crab Orchard Creek.

the draining of floodplain wetlands and clearing of riparian areas. Early in the 20th century, large-scale extraction of bituminous coal badly polluted tributaries of the upper and middle reaches of the river with silt and acid runoff; these problems plague the drainage to this day. More recently, construction of impoundments destroyed miles of stream habitat, altered natural discharge patterns, blocked migration of large-river fishes, and isolated many small-stream fish communities in headwaters of embayed tributaries.

Over 50% of the Big Muddy River drainage is in agriculture, much of which is under intensive tillage and subject to severe erosion. The drainage, nevertheless, serves as a major center in Illinois for water-based activities such as boating, fishing, waterfowl hunting, and camping. These activities are supported in part by three moderate to large reservoirs in the drainage—Rend, Crab Orchard, and Kincaid lakes—as well as numerous smaller impoundments. Rend Lake, in Franklin and Jefferson counties, is the second largest inland impoundment in the state. Recreational activity in the drainage is multifaceted and not strictly reservoir-based, being focused also around unique natural features or managed multiple-use areas such as the Shawnee National Forest (including Oakwood Bottoms), Crab Orchard National Wildlife Refuge, Giant City State Park, Little Grand Canyon, and Panther Den Wilderness.

In compiling our review of the drainage, we found (not surprisingly) that the fish fauna of the Big Muddy River drainage has been sampled systematically using standard methods in only a limited manner, but there is a considerable body of data on fisheries of the basin's reservoirs. We chose not to review the reservoir fisheries but refer the interested reader to Whitacre (1952), Allen and Wayne (1974), and Garver (1970, 1974). From a riverine standpoint, integrated, long-term ecological studies of the mainstem and large tributaries are noticeably lacking. In that vein, the work of Atwood (1988) and Hite et al. (1991) provides a much-needed foundation for beginning to understand the ramifications of anthropogenic change on the river's ecology.

Nevertheless, owing to a long history of collection of fishes in streams of the drainage, the native fish fauna is reasonably well-known and documented in regional and national fish collections. We assembled these data on the fish fauna of the Big Muddy River drainage into five eras of collecting activity. The first investigations date back to the classical work on Illinois fishes by Forbes and Richardson (1908), who reported on at least 12 collections made in the drainage during a period from about 1892 to 1900. From 1939 to 1940, A. C. Bauman, a former student of C. L. Hubbs, then at the University of Michigan, made 10 fish collections in the drainage. Beginning in the early 1950's, W. M. Lewis, Sr. and his students conducted several aquatic studies in the drainage and made at least 30 fish collections. The most comprehensive sampling of the Big Muddy River was by P. W. Smith and his colleagues, from 1963 to 1978, which resulted in 65 collections from throughout the drainage (Smith 1979). More recent efforts (1980–92), under the auspices of one of us (B. M. Burr), have resulted in 55 collections and the discovery of several fishes previously unreported from the drainage.

With this background, our primary objective is to present a description of the Big Muddy River drainage and its fish fauna, historically and today. We also identify impacts that have detrimentally affected the entire native aquatic community, provide a basic outline of management and monitoring needs for the river, and summarize requirements for restoration of the aquatic riverine resources in the drainage.

Sources and Methods

Information on the fish fauna of the Big Muddy River has been drawn from a variety of sources: (1) the primary literature—Forbes and Richardson (1908), Lewis (1955), Stegman (1959), Smith (1971, 1979), Burr and Page (1986), Warren and Burr (1988, 1989), and Burr (1991); (2) the gray literature—Whitacre (1952), Price (1965), Atwood (1988), Davin and Sheehan (1991), Hite et al. (1991), Burr et al. (1992), and Page et al. (1992); (3) vouchered specimen records in museum or university collections—University of Michigan Museum of Zoology, Illinois Natural History Survey, and Southern Illinois University at Carbondale; and (4) personal knowledge and field experience in the drainage over the past 20 years.

Physical, geological, and chemical features of the drainage were compiled from Rolfe (1908), Walker (1952), Schuster (1953), Price (1965), Smith (1971), Lopinot (1973), Illinois Environmental Protection Agency (1976), Ogata (1975), Hite and Bertrand (1989), Hite et al. (1991), and Illinois Environmental Protection Agency (1992). Streams, communities, and counties mentioned in the text are identified in Fig. 1.

Only limited standard sampling emphasizing catch per unit effort (CPUE) has been conducted on the fish fauna of the drainage. We assessed sampling effort from fish collections made over the past 100 years by competent fish biologists searching for maximum fish diversity in all available habitats at about 100 record stations in the drainage (Fig. 2). As already noted, we recorded sampling effort for different periods (eras), with credit given to the individuals making the most collections or directing the most effort during a given era (Table 1). Techniques used to sample fish over the years have included hook-and-line; wing, hoop, and gill nets; electrofishing; rotenone; and seining with various size nets and meshes. For purposes here, a collection is defined as thorough sampling of available habitats at a given locality using a variety of methods. Unfortunately, amount of effort and specific gear type at a given locality are largely unknown for collections made near the turn of the century and through the 1960's. It is therefore not possible to compare CPUE at a given site with the same gear type for one species.

The Big Muddy River Drainage

General Features

The Big Muddy River, one of the principal tributaries of the Mississippi River in southwestern Illinois, drains an area of 6,182 km^2 (Ogata 1975). The river's somewhat elliptical basin extends 168.9 km from north to south and 112.6 km from east to west (Lewis 1955), with a median length of 115.8 km and an average width of 53.1 km (Hite et al. 1991). Major tributaries within the Big Muddy River drainage include Casey Fork, Middle Fork, and Little Muddy River; and Crab Orchard, Galum, Kincaid, Cedar, and Beaucoup creeks (Fig. 1). The drainage includes the greater part of Franklin, Jackson, Jefferson, Perry, and Williamson counties; the southeastern portion of Washington County; the northern portions of Union and Johnson counties; the western edge of Hamilton County; and the southern part of Marion County (Fig. 1).

Four natural divisions are encompassed—Lower Mississippi River Bottomlands, Ozark, Shawnee Hills, and Southern Till Plain (Schwegman 1973). The Southern Till Plain composes most of the basin. The drainage lies at the extreme southwestern edge of the district covered by the Illinoisan drift sheet, lying in the low section just north of the Ozark ridge. The drainage is characterized by hilly upland topography and broad flat lowlands along the principal streams. The lower 32.2 km of the river flows through the Mississippi River Bottomlands. With the exception of the Ozark ridge on the southern border, which stands 182–243 m above mean sea level, the basin has few points rising above 167 m, the average level being 122–152 m. The immediate borders of the main valley fall below 122 m, and the mouth of the stream at low water in the Mississippi River is about 97 m. The bank-full channel of the mainstem throughout most of its course is 8–15 m wide and 15–21 m deep. A few sandstone outcrops, a common stratum in five of eight of the river's principal tributaries, and some patches of gravel are found in the main channel.

The Big Muddy River has the characteristics of an old stream, in an area long exposed to erosion (Rolfe 1908). Its bed has been cut down to drainage level, and its sinuous course runs over a broad floodplain. The river originates in northernmost Jefferson County and flows directly south and then generally southwest to empty into the Mississippi River about 8 km downstream from Grand Tower in Jackson County, at river km (rkm) 122 (Fig. 1). The length of the river, estimated from its point of origin, is about 248 km (Hite et al. 1991). Beaucoup Creek enters from the north about 40–48 km from the mouth, and Little Muddy River enters from the same side about 16 km farther upstream. These two streams together (2,222 km^2) drain about the same area as the mainstem above the Little Muddy River confluence. Beaucoup Creek (1,487 km^2) drains about twice the area of the Little Muddy River (736 km^2). An eastern tributary—Crab Orchard Creek—enters the mainstem from the south between the mouths of Beaucoup Creek and Little Muddy River and drains about 749 km^2 of the area bordering the Ozark ridge.

Hydrography

The Big Muddy River mainstem is at least as sluggish today as it was over a century ago (Rolfe 1908). Increased erosion and drainage of lowlands have exacerbated the silt load in the mainstem. Historically, in times of spring flood, Rolfe (1908) noted heavy silt loads that rendered the bottom a "creeping mass, shifting its contour with every change in rate of flow"; conversely, during summer drought the mainstem was reduced to a series of nearly stagnant pools. The river is properly named because with the exception of riffle areas the

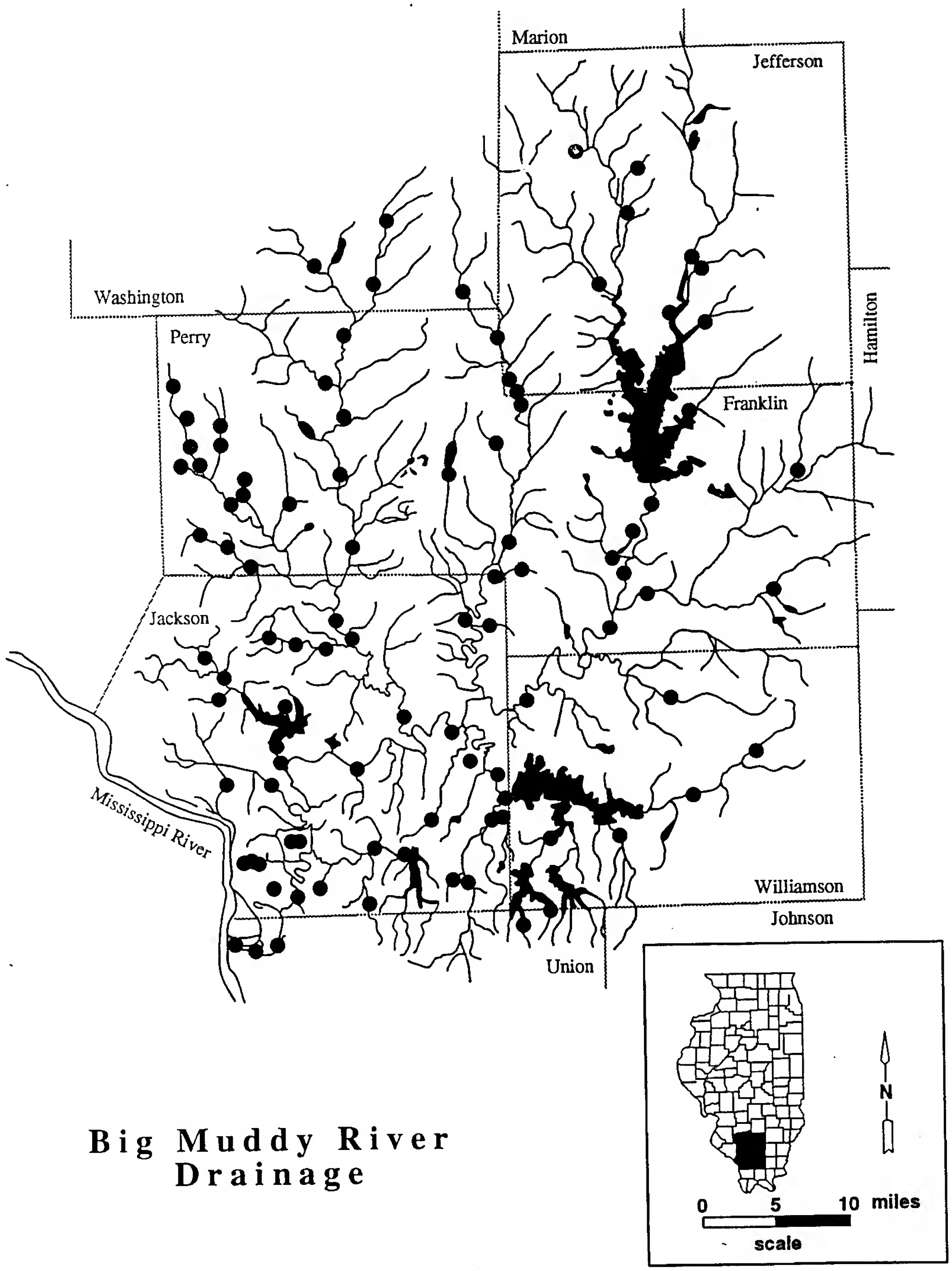

Fig. 2. Map of fish sampling sites in the Big Muddy River drainage represented in the Illinois Natural History Survey, University of Michigan Museum of Zoology, and Southern Illinois University at Carbondale ichthyological collections. Approximately 100 sites have been sampled at least once from 1892 to 1992.

Table 1. Fishes recorded from the Big Muddy River drainage, Illinois, in the period 1892–92, categorized by major historical periods of sampling. Classification and nomenclature of fish species follows Page and Burr (1991) VN = vouchered with a museum specimen and native to the drainage; I = introduced fish species deliberately or inadvertently moved into the drainage; L = literature record considered valid, species regarded as native; IE = introduced fish species with established population; IPE = introduced fish species without the status of a permanent population, but reproducing in an area where its elimination by humans would be impractical; R = record of an introduced fish species without evidence of reproduction, and vouchered with a museum specimen. Numbers in parentheses are number of collections made during a given period. SE = Illinois State Endangered; ST = Illinois State Threatened.

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
Petromyzontidae					
1. *Ichthyomyzon castaneus*			VN		
Acipenseridae					
2. *Scaphirhynchus platorynchus*				VN	
Polyodontidae					
3. *Polyodon spathula*				VN	VN
Lepisosteidae					
4. *Atractosteus spatula* ST	L				
5. *Lepisosteus oculatus*					VN
6. *L. osseus*	L		L		
7. *L. platostomus*			L	VN	VN
Amiidae					
8. *Amia calva*	VN		VN	VN	VN
Anguillidae					
9. *Anguilla rostrata*			L		
Clupeidae					
10. *Alosa chrysochloris*			VN	VN	
11. *Dorosoma cepedianum*		VN	VN	VN	VN
12. *D. petenense*				VN	VN
Hiodontidae					
13. *Hiodon alosoides*			VN	VN	VN
Salmonidae					
14. *Oncorhynchus mykiss* I					IPE
Umbridae					
15. *Umbra limi*	L			VN	VN
Esocidae					
16 *Esox americanus*	VN	VN	VN	VN	VN
17. *E. lucius* I					IE
18. *E. masquinongy* I					IE
Cyprinidae					
19. *Campostoma anomalum*	L	VN	VN	VN	VN
20. *Ctenopharyngodon idella* I					IPE
21. *Cyprinella lutrensis*	VN	VN	VN	VN	VN
22. *C. spiloptera*					VN
23. *C. venusta*		VN			
24. *C. whipplei*	L	VN	VN		
25. *Cyprinus carpio* I	IE	IE	IE	IE	IE
26. *Ericymba buccata*		VN	VN	VN	
27. *Hybognathus hayi* SE		VN			
28. *H. nuchalis*	VN	VN		VN	VN
29. *Hybopsis amnis* SE	VN	VN			
30. *Hypophthalmichthys nobilis* I					IPE

Table 1. *Continued.*

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
31. *Luxilus chrysocephalus*	L	VN			
32. *Lythrurus fumeus*		VN		VN	VN
33. *L. umbratilis*	L	VN	VN	VN	VN
34. *Macrhybopsis storeriana*	L				
35. *Notemigonus crysoleucas*	VN	VN	VN	VN	VN
36. *Notropis atherinoides*	VN	VN	VN	VN	VN
37. *N. blennius*	L				VN
38. *N. ludibundus*		VN	VN	VN	VN
39. *N. shumardi*		VN		VN	VN
40. *N. volucellus*		VN	L		VN
41. *Opsopoeodus emiliae*	VN	VN		VN	VN
42. *Phenacobius mirabilis*	L	VN	VN	VN	VN
43. *Pimephales notatus*	VN	VN	VN	VN	VN
44. *P. promelas*					VN
45. *P. vigilax*	VN	VN	VN	VN	VN
46. *Platygobio gracilis*				VN	
47. *Semotilus atromaculatus*	VN	VN	L	VN	VN
Catostomidae					
48. *Carpiodes carpio*		VN	VN		
49. *C. cyprinus*		VN	VN		VN
50. *Catostomus commersoni*		VN	VN	VN	VN
51. *Cycleptus elongatus*			L		
52. *Erimyzon oblongus*	VN	VN	VN	VN	VN
53. *E. sucetta*				VN	
54. *Hypentelium nigricans*				VN	
55. *Ictiobus bubalus*			VN	VN	
56. *I. cyprinellus*		VN	VN	VN	VN
57. *I. niger*				VN	VN
58. *Minytrema melanops*	L	VN	VN	VN	VN
59. *Moxostoma erythrurum*		VN	VN	VN	VN
60. *M. macrolepidotum*					VN
Ictaluridae					
61. *Ameiurus melas*	VN	VN	VN	VN	VN
62. *A. natalis*	L	VN	VN	VN	VN
63. *A. nebulosus*			VN		
64. *Ictalurus furcatus*			L		
65. *I. punctatus*	L	VN	VN	VN	VN
66. *Noturus gyrinus*	VN	VN	VN	VN	VN
67. *N. nocturnus*					VN
68. *Pylodictis olivaris*			VN		VN
Percopsidae					
69. *Percopsis omiscomaycus*		VN			
Aphredoderidae					
70. *Aphredoderus sayanus*	VN	VN	VN	VN	VN
Amblyopsidae					
71. *Forbesichthys agassizi*					VN
Gadidae					
72. *Lota lota*			L		
Fundulidae					
73. *Fundulus notatus*	VN	VN	VN	VN	VN
74. *F. olivaceus*	VN	VN		VN	VN
Poeciliidae					

Table 1. *Continued.*

Family Species	S. A. Forbes and R. E. Richardson 1892–1900 (12)	A. C. Bauman 1939–40 (10)	W. M. Lewis 1950–59 (30)	P. W. Smith 1963–78 (65)	B. M. Burr 1980–92 (55)
75. *Gambusia affinis*		VN	VN	VN	VN
Atherinidae					
76. *Labidesthes sicculus*					VN
77. *Menidia beryllina*					VN
Moronidae					
78. *Morone chrysops*	L		L	VN	VN
79. *M. mississippiensis*			L	VN	VN
80. *M. saxatilis* I				R	R
Centrarchidae (Percichthyidae)					
81. *Centrarchus macropterus*	VN		VN	VN	VN
82. *Lepomis cyanellus*		VN	VN	VN	VN
83. *L. gibbosus* I					R
84. *L. gulosus*	VN	VN	VN	VN	VN
85. *L. humilis*	VN	VN	VN	VN	VN
86. *L. macrochirus*	L	VN	VN	VN	VN
87. *L. megalotis*	L	VN	VN	VN	VN
88. *L. microlophus*				VN	VN
89. *Micropterus punctulatus*			L	L	VN
90. *M. salmoides*	VN	VN	VN	VN	VN
91. *Pomoxis annularis*	L	VN	VN	VN	VN
92. *P. nigromaculatus*	VN	VN	VN	VN	VN
Percidae					
93. *Etheostoma asprigene*	L	VN		VN	VN
94. *E. chlorosomum*	VN	VN	L	VN	VN
95. *E. flabellare*		VN	VN	VN	VN
96. *E. gracile*	VN	VN	L	VN	VN
97. *E. nigrum*	L	VN	VN	VN	VN
98. *E. proeliare*		VN		VN	
99. *E. spectabile*		VN	VN	VN	VN
100. *Perca flavescens* I					IPE
101. *Percina caprodes*		VN	VN	VN	VN
102. *P. maculata*	L	VN	VN	VN	VN
103. *P. shumardi*		VN	VN	VN	VN
104. *Stizostedion canadense*			VN	VN	
105. *S. vitreum*			VN	VN	
Sciaenidae					
106. *Aplodinotus grunniens*	L	VN	VN		VN
Total native species	45	58	65	68	71
Total introduced species	1	1	1	2	9
Total species	46	59	66	70	80

substrate of the mainstem and many tributaries is composed of thick layers of silt and mud. In the first 18 km from its origin the gradient is nearly 3 m/km, but ranges from less than 0.3 m/km in the middle reaches to 0.06 m/km at the confluence with the Mississippi River.

Major impoundments and the draining of wetlands have altered the hydrology of the watershed over the past 100 years. Flows have been decreased, especially on tributaries, and the timing and extent of flood pulses have been disrupted on the mainstem. Average daily stream flow for a 259-km^2 area ranges from 0.80 cubic feet per second (cfs) in the northwestern part of the drainage to 1.1 cfs in the southeastern part (Illinois Environmental Protection Agency 1976). Seven-day, 10-year low flows on

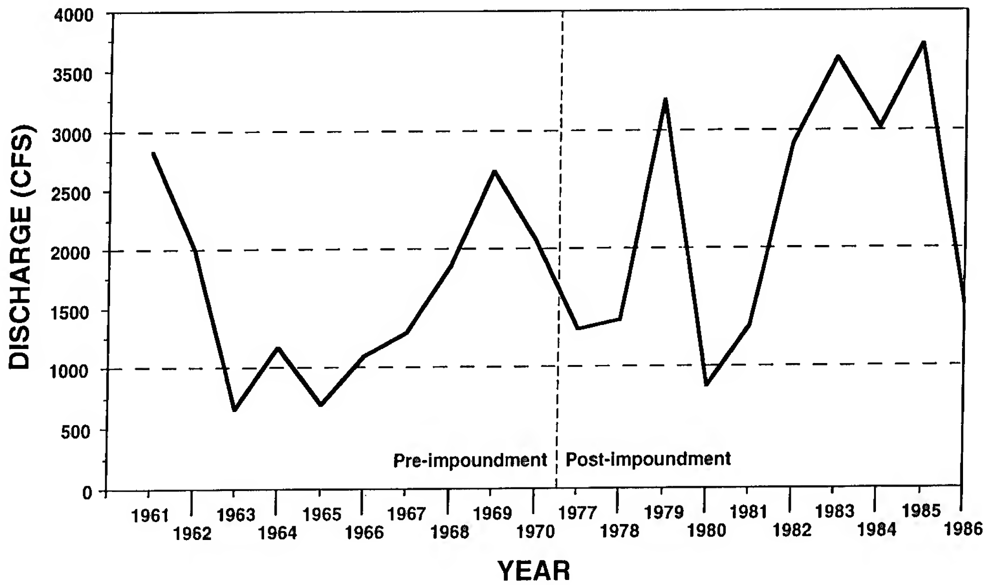

Fig. 3. Mean annual discharge pattern of the Big Muddy River as recorded by U.S. Geological Survey at the Murphysboro gaging station for a 10-year period (1961–70) before completion of Rend Lake and a 10-year period (1977–86) after completion of Rend Lake.

gaged streams in the drainage range from 0.0 cfs on several intermittent streams to 36.3 cfs on the mainstem near its mouth (Singh and Stall 1973). The rather extreme sinuosity of the Big Muddy River channel, a total fall of only 94 m, and an overall low gradient are the primary physical attributes collectively responsible for low stream velocities (U.S. Corps of Engineers 1968). Mean annual discharge recorded at the Murphysboro gaging station (Fig. 3) varied from 664 cfs in 1963 to 2,821 cfs in 1961 before completion of Rend Lake in 1970. After completion of Rend Lake, mean annual discharge varied from 839 cfs in 1980 to 3,599 cfs in 1983. Mean annual discharge does not appear to have stabilized since the lake was filled; however, this does not take into account the timing of the pulse and flow pattern during the spring.

Throughout the greater portion of its course, the Big Muddy River meanders about in a broad floodplain that is filled with drift and alluvium to a depth of 152–182 m or more above the bedrock. Upstream from Murphysboro (Fig. 1), the banks are neither abrupt nor high, and they and the bed of the stream are chiefly clay. Just below Murphysboro, the valley becomes constricted to a width of about 1.6 km as it breaches the elevated ridge that borders the Mississippi River. In its course through the Mississippi River Bottomlands its eastern shore hugs the ridge with a line of bluffs that rise 61–71 m above the river. On its west is the low, flat floodplain of the Mississippi River.

At Murphysboro (Fig. 1), where the channel is about 49 m wide, the water has sometimes risen 9 m, inundating the surrounding flats. Backwater from the Mississippi River is felt at that point and may even extend 138 km upstream to the vicinity of Plumfield (Hite et al. 1991).

Annual average rainfall of 106.7 cm and runoff of 31.8 cm, as well as soils of low permeability, make the Big Muddy River drainage suitable for surface water storage in reservoirs (U.S. Department of Agriculture 1968). Major impoundments in the drainage, all constructed since 1940, include Rend Lake (7,655 ha, completed in 1970), Crab Orchard Lake (2,821 ha, completed in 1940), Devil's Kitchen Lake (328 ha, completed in 1959), Little Grassy Lake (405 ha, completed in 1942), Cedar Lake (729 ha, completed in 1973), and Kincaid Lake (1,400 ha, completed in 1970). Numerous municipal reservoirs occupy smaller portions of the drainage. Rend Lake is an important source of flow in the Big Muddy River, providing a year-round flow of at

least 30 cfs as required by the U.S. Army Corps of Engineers.

Physiography

About 90% of the Big Muddy River drainage is located in the physiographic subdivision termed the Mount Vernon Hill Country of the Central Lowland Province (Leighton et al. 1948). Most of the remaining land area, the southwestern part of the basin, is in the Shawnee Hills section of the Interior Low Plateaus Province, which joins the Ozark Mountains in Missouri and Arkansas. A small portion of the drainage lies on the Mississippi River floodplain.

The Mount Vernon Hill Country is characterized by low rolling hills and broad alluvial valleys along the major streams. The relief in this region is not pronounced. Upland prairies are flat to moderately hilly, and the valleys are shallow. The land surface is controlled primarily by bedrock, which has been modified only slightly by glacial drift deposits. While the southern boundary of the Mount Vernon Hill Country lies within a few kilometers of the limits of glaciation, moraine ridges essentially are absent in the area.

The Shawnee Hills are south and southwest of the Mount Vernon Hill Country and provide striking contrast to that region. This section is unglaciated and characterized by rocky ridges and deep valleys. This area displays a complex, bedrock-controlled topography.

In its lower 32 km, the Big Muddy River flows on the Mississippi River floodplain. The floodplain is nearly flat except where it is broken by an outcrop of bedrock—Fountain Bluff—which rises about 122 m above the river channel at its base.

Geology

The entire Big Muddy River drainage lies in a preglacial valley. Over the greater portion of the area the drift is thin, and rock divides separating the preglacial drainages are plainly visible. During the Pleistocene, meltwaters from receding glaciers caused the Mississippi River to exceed its transporting capacity. The Mississippi valley filled with sediment deposits that closed the mouths of some tributary streams. The Big Muddy River, one of the impounded tributaries, formed a lake. When the Mississippi River was once more able to transport, the natural process of downcutting occurred, and the Big Muddy Lake was drained. Typical of a lake bed long subject to erosion, the soils of the Big Muddy River drainage contain little humus, are acidic, and consist of impervious clays and silts, interlaced with very fine sands (LeTellier 1971).

The Big Muddy River drainage is in the southern part of the geologic structure known as the Illinois Basin. Over most of the basin the bedrock lies nearly flat, sloping gently toward the east. The Pennsylvanian bedrock underlies about 80% of the basin and in places reaches thicknesses of 790 m. It generally is composed of shale, sandy shale, and sandstone interbedded with thin limestone layers and coal. A small area of Mississippian, Devonian, and Silurian bedrock occurs in the southwestern portion of the basin. The Devonian and Silurian bedrock consists of limestones and sandstones that, together with Pennsylvanian rocks, uplifted and formed portions of the Shawnee Hills.

Bedrock in the basin is overlain by discontinuous deposits of Pleistocene glacial till, a clay-rich slowly permeable material. Uplands may be mantled with up to 7.6 m of loess (a moderately to slowly permeable silty soil), the depth and permeability of which decrease from southwest to northeast across the basin. The loess, a highly erodible soil, is about 0.6 m thick at the upstream border of the basin and increases to 6 m near the mouth of the Big Muddy River (U.S. Department of Agriculture 1968). The stream valleys contain alluvium and lake clays, generally with low permeability and high water table levels. The Mississippi River floodplain, a small part of the drainage, contains deposits of outwash consisting of sand and gravel interbedded with layers of silt and clay. In addition, occasional small granular deposits such as alluvium, dune sand, and various types of glacial outwash deposits may be found in the basin.

Land Use

Cropland, forest, and pastureland are the predominant land uses in the central and lower Big Muddy River drainage, composing 51.5%, 24.5%, and 12.6%, respectively (U.S. Department of Agriculture 1968). The remaining 11.4% includes urban areas, industrial sites,. residential areas, roads, coal mines, and oil fields. About 2% of the basin has been strip-mined for coal, and many areas have not been reclaimed. Gob and other waste materials are exposed on numerous old underground coal mine sites in Franklin County; these areas continue to contribute to water quality problems associated with acid runoff (Hite et al. 1991).

Substantial changes in the regional landscape have occurred since the time of settlement. In 1820, the five principal counties drained by the Big Muddy River were composed of 518,805 ha of forest and 124,132 ha of prairie (Iverson et al. 1989). By 1924 forested acreage was reduced to 109,796 ha (Iverson et al. 1989).

Mainstem Habitat

During August 1988, a period of near record low-flow conditions, the Illinois Environmental Protection Agency (Hite et al. 1991) collected a variety of habitat data that in our experience typifies the Big Muddy River mainstem. The mainstem averaged about 25 m wide and 0.73 m deep. Stream discharge ranged from 44 cfs west of Benton (just below the Rend Lake tailwaters) to 63 cfs at a downstream site near Murphysboro. Mean velocity at five sites was 0.12 m/s. The mean percentage of pool was 60.6 and of riffle 2.1. Average instream cover was about 8.8%; shading was sparse to moderate at 27%. Silt-mud (33.5%) was the predominant bottom substrate, followed by gravel (28.8%), plant detritus (10.6%), submerged logs (7.0%), cobble (6.9%), claypan-compacted soil (6.6%), sand (5.1%), boulders (1.2%), and other substrates. In comparison with other Illinois streams (e.g., Kaskaskia River to the north), the Big Muddy River had the highest means for width, depth, discharge, percent pool, and percent silt-mud—all characteristics of a low-gradient stream.

Natural Resources

The major natural resources available in the Big Muddy River drainage are soil, minerals, forests, and surface water. Groundwater supplies are scanty and of poor quality except along the extreme western edge of the drainage. The widespread construction of impoundments has provided adequate water supplies throughout the basin (Illinois Environmental Protection Agency 1976).

The principal mineral resources in the basin are coal and oil. These two commodities are in active production and are shipped from the area in quantities sufficient to make the Big Muddy River drainage a leading fuel-producing region. Pennsylvanian coal layers have been mined extensively for over a century, with production peaking from the late 1950's to the early 1970's. Coal reserves are substantial and probably exceed 15 billion metric tons.

Oil pools are known to exist in Franklin, Hamilton, Jefferson, and Washington counties. Most of the basin's oil production is from fields in Franklin and Jefferson counties. Estimated oil reserves in these two counties exceed 40 million barrels.

Other mineral resources in the basin are sand, gravel, limestone, sandstone, clay, and shale. These commodities are not recovered in large amounts, and production is used to supply local demands.

Water Quality and Environmental Impacts

As noted previously, pollution within the basin is associated with the various discharges and conditions inherent to coal mining and oil recovery as well as industrial and domestic effluent (Price 1965). The various forms of pollution and other environmental impacts (i.e., impoundments) are categorized below.

Drought

Extremely low flows during summer months and concomitant pooling of the mainstem were reported by early observers in the basin (Rolfe 1908). However, in recent decades the water table in Illinois has fluctuated more widely than it did before 1930 (Smith 1971). During some of the worst droughts affecting the basin (late 1980's), once permanently flowing streams dried up, seeps and springs ceased flow, and the mainstem temporarily became a medium-sized or even small stream. The effects of the most recent (1988) drought included massive fish kills in tributary streams primarily because of oxygen depletion.

Municipal and Industrial Discharges

Inadequate domestic sewage treatment, as well as discharges from various industries, accounts for poor water quality in some areas of the basin, particularly downstream of Rend Lake. Twelve communities have a population of 3,000 or greater, and 11 of these lie downstream of Rend Lake, discharging wastewater either directly into the mainstem or into tributaries (Hite et al. 1991). Numerous other point and nonpoint sources, including small wastewater treatment plants, industrial sites, and active and inactive coal mines, discharge nutrients, metals, and other constituents directly

or indirectly into the lowermost 167 km mainstem of Big Muddy River.

Historically, these discharges have degraded water quality and aquatic life in the river, particularly during periods of low flow. Early studies conducted by students of W. M. Lewis, Sr. at Southern Illinois University at Carbondale concluded that toxic pollution in the drainage was spasmodic and localized and that the most toxic conditions were confined to tributaries. The major pollutants in the early 1950's were sewage, creosols, silt, garbage wastes, iron, acid-mine drainage, and other coal-mine wastes (Walker 1952; Schuster 1953). Fish kills were documented on several occasions in the Crab Orchard Creek drainage near a railroad cross-tie plant, where creosote accumulation was washed into the creek during rainy periods (Lewis 1955). Price (1965) recorded a pH below 3.0, black water with frequent gas bubbles, and no fish near a municipal sewage discharge in Crab Orchard Creek about 8 stream km above the head of Crab Orchard Lake. Effluent sampling conducted in 1988 from 10 municipal wastewater treatment plants (Hite et al. 1991) revealed considerable variability in many parameters; however, phosphorus, un-ionized ammonia, and chemical oxygen demand were elevated more frequently than other constituents. In recent years, however, all major wastewater treatment plants that discharge to the lower Big Muddy River drainage have renovated or plan to upgrade treatment facilities through the state grant construction program (Hite et al. 1991). Because 70% of these plants have now made structural improvements in existing facilities, higher quality effluent would be expected in future studies.

Coal Mine Discharge

The presence of large waste piles from surface and underground mining presents a constant source of potential and oft-realized pollution in the drainage. Mining pollution was particularly acute during the 1950's and 1960's before the advent of regulation and reclamation. Although extensive mining activities are present in other Big Muddy River tributaries, including the Little Muddy River and Beaucoup Creek, the majority of mine drainage originates in Franklin and Williamson counties. Twenty-four mine discharges, permitted under the National Pollutant Discharge Elimination System, shunt effluent to the lower Big Muddy River or tributaries downstream from Rend Lake in Franklin and Williamson counties. Discharge types include surface runoff, reclamation runoff, pit pumpage, underground pumpage, untreated acid mine drainage, and treated acid mine drainage. At least nine known unpermitted and untreated mine discharges also release acid waters to the Big Muddy River in Franklin and Williamson counties (Hite et al. 1991). Runoff from the numerous spoil piles has resulted in water of undesirable quality flowing into the drainage. The pumping of water from old strip mines to rework the strip area for additional coal often results in even poorer quality water being discharged into waterways.

In 1964, Illinois Department of Conservation fishery biologist O. M. Price sampled Lake and Pond creeks, Williamson County (see Fig. 1) and recorded pH values of 3.5, a bright orange precipitate on the stream bottom and shoreline, and no fish at either station. In Lake Creek, a water velocity of over 0.15 m/s through a channel averaging 7.6 m in width and 0.6 m in depth, represented a considerable volume of polluted water flowing into the nearby mainstem. Fish kills from acidic waters continue to this day; the Illinois Environmental Protection Agency investigated a series of fish kills near Royalton on the Big Muddy River and in Prairie Creek from 1988 to 1990. The agency recorded pH values as low as 2.5 and high manganese concentrations in the Royalton drinking water (Hite et al. 1991). These problems are directly attributable to several mines just upstream of Royalton. Plans are underway for reclamation of these sites.

Water Quality

Water quality as measured at 27 sites on the mainstem and tributaries by Illinois Environmental Protection Agency personnel (Hite et al. 1991) during 1988 revealed that negative effects originated largely from municipal effluents and runoff from coal mines and agricultural activities. Water quality in 1988 generally was rated as borderline between fair/good and poor, although very good and very poor water also existed. Very good water was noted immediately downstream of Rend, Crab Orchard, and Kincaid lakes, which was indicative of reservoir trapping efficiency, specifically for nutrients and suspended solids. This effect was evident in the tailwaters of the major impoundments relative to water quality elsewhere in the basin. Very poor water was rare in the mainstem and more prevalent in tributaries. Middle Fork and its tributary, Ewing Creek, displayed

the poorest water. Water quality in these two streams was influenced largely by runoff from abandoned mines in the Middle Fork watershed. Illinois General Use Water Quality Standard violations were common in the Big Muddy River and tributaries but were not generally extreme. The standard most often violated was for manganese, followed by dissolved oxygen and then sulfate. The standard for pH was often violated; however, violations of these standards were limited to Big Muddy River tributaries (Hite et al. 1991).

Oil Pollution

Smith (1971) noted that oil-field pollution had been a problem in the Big Muddy River drainage for many years. There seems, however, to be little documentation of oil brine pollution affecting the fishes in the drainage. Price (1965) observed oil scum on the water surface, as well as on the shoreline vegetation, and debris in Galum Creek and the Middle Fork. Both of these sites contained poor fish diversity (8 and 13 species, respectively), and the fish assemblages were dominated by tolerant species (i.e., red shiner [*Cyprinella lutrensis*], redfin shiner [*Lythrurus umbratilis*], western mosquitofish [*Gambusia affinis*], bluegill [*Lepomis macrochirus*]).

Siltation, Stream Dredging, and Wetland Drainage

The cycle of poor soil conservation practices accelerating stream siltation, which in turn provides impetus for dredging, draining, and channelization projects, has plagued aquatic habitats in the basin for some time (Price 1965). The results include loss of adequate woody riparian corridors, loss of perennial and ephemeral riparian wetlands, a decrease in low flows (especially in tributaries), degradation of the floodplain, blockage of high flow channels, and homogenization of in-stream habitats. According to Smith (1971) excessive siltation ranks first in Illinois as the principal factor responsible for changes in fish populations. Its effects include loss of water clarity and subsequent disappearance of aquatic vegetation, and the deposition of silt over substrates that were once bedrock, rubble, gravel, and sand. Feeding and spawning sites have surely been reduced by siltation in the Big Muddy River drainage in this century. Likewise, the draining of floodplain wetlands has eliminated specialized spawning and nursery habitats for some fishes and reduced the primary habitat for others (see section on extirpated fishes). Smith (1971) ranked the drainage of wetlands as the second most important factor responsible for changes in fish populations in Illinois. At least 80 stream km of the Big Muddy River drainage have been channelized (Lopinot 1972), allegedly for flood control and to increase arable land. The effects of channelization include the straightening of natural stream meanders, denuding of the banks, and widening and deepening of the channel. The change in substrate and loss of instream cover and shade from channelization have resulted in stream fish communities represented by only the most tolerant species. Given the historical evidence that the mainstem generally carried a heavy silt load and often pooled up in the summer, we speculate that the effects of these factors on fishes were probably most severe in the river's tributaries.

Garbage

Various streams in the Big Muddy River drainage have been the dumping grounds for human garbage for many years (Walker 1952). While this irresponsible behavior results in an aesthetically unappealing and perhaps unhealthy environment, it is difficult to assess the long-term ecological effects of such abuse on the fish fauna.

Impoundments

The richness of the Big Muddy River fish fauna presumably is related directly to the number of different habitats available (Smith 1971). Flowing streams consist of alternating riffles and pools, each of which has many distinct microhabitats formed by various permutations of substrate type, depth, cover, and velocity. When the river and its tributaries were impounded, riffles and their respective microhabitats were eliminated and, in the shallow reservoirs of the Big Muddy River drainage (e.g., Rend Lake), the bottom was covered quickly with silt, resulting in only one basic fish habitat. Dams constructed to form impoundments also blocked natural migration and dispersal of fishes. Historically, the blue sucker (*Cycleptus elongatus*) was known to make spring spawning runs up the Big Muddy River; it has not been reported in the drainage since the 1950's (Lewis 1955). The paddlefish (*Polyodon spathula*) has been observed in the tailwaters of Crab Orchard and Rend lakes, but their dams prevent further upstream migration and spawning that may have occurred historically. Although preimpoundment

data generally are lacking and distributional information is scant (Smith 1979), we suspect that dam construction also impeded spring spawning runs of important sportfishes in the river, such as walleye (*Stizostedion vitreum*), white bass (*Morone chrysops*), and perhaps yellow bass (*Morone mississippiensis*), and hence diminished the potential of the river's fishery. As noted previously, there are numerous small, medium, and large reservoirs in the Big Muddy River drainage. Unfortunately, the construction of Cedar, Kincaid, Little Grassy, and Devil's Kitchen lakes destroyed some of the least affected and most aesthetically pleasing streams in the drainage.

Because of the basin's pollution history, some impoundments have exhibited elevated levels of trace metals in the fish populations, particularly mercury. In the past decade biomagnification of mercury in the flesh of various sportfishes was reported from Crab Orchard, Cedar, and Kincaid lakes (Call 1989). Call (1989) pointed out, however, that the sediments in these lakes ultimately may serve as a sink for trace metals, and thereby aid in mitigation of biological effects.

The Fish Fauna

General Faunal Composition

A total of 106 fish species, representing 25 families, has been recorded from the Big Muddy River drainage from 1892 to 1992 (Table 1). Of these, 97 species are considered native, and 9 occur in the drainage as a result of introductions of exotics or transplantations of species native to other parts of the continent. Just over half (51.9%) the total (187 species) native fish fauna known from Illinois (Burr 1991) occur in the Big Muddy River drainage. The native fish fauna of the drainage constitutes just over one-fourth of the 375 freshwater fishes found in the Mississippi River basin (Burr and Mayden 1992). The five dominant families are Cyprinidae (26 species), Catostomidae (13 species), Percidae (12 species), Centrarchidae (11 species), and Ictaluridae (8 species); in total they comprise 72% (70 species) of the native fauna. The families Petromyzontidae, Acipenseridae, Polyodontidae, Amiidae, Anguillidae, Hiodontidae, Umbridae, Percopsidae, Aphredoderidae, Amblyopsidae, Gadidae, Poeciliidae, and Sciaenidae are each represented by one extant native species.

The Kaskaskia River, the next major river drainage (15,022 km^2) to the north of the Big Muddy River, has at least 103 native species, and the Cache River, a major river drainage (2,717 km^2) to the south of the Big Muddy River, has at least 71 native species (Burr and Page 1986). Adjusting for catchment size (species per kilometer^2), the Big Muddy River drainage with about 0.02 species/km^2 has over twice the species density of the larger Kaskaskia River drainage (0.007) and slightly more than half that of the smaller Cache River drainage (0.03). Differences in catchment size, habitat diversity, and geological history are among the most important factors influencing native species diversity in the upper Mississippi River basin (Burr and Page 1986), and almost certainly account for the differences in native species diversity and density among the Big Muddy, Cache, and Kaskaskia rivers.

Unusual fishes known from the drainage that are apparently year-round residents with limited ranges in Illinois (Smith 1979) include the paddlefish, spotted gar (*Lepisosteus oculatus*), central mudminnow (*Umbra limi*), Mississippi silvery minnow (*Hybognathus nuchalis*), pugnose minnow (*Opsopoeodus emiliae*), lake chubsucker (*Erimyzon sucetta*), shorthead redhorse (*Moxostoma macrolepidotum*), freckled madtom (*Noturus nocturnus*), spring cavefish (*Forbesichthys agassizi*), mud darter (*Etheostoma asprigene*), and river darter (*Percina shumardi*). Exposed rock riffles during low flow on the mainstem near Murphysboro and at Rattlesnake Ferry often yield 25–30 species, including nearly all of the species listed above.

Unsubstantiated or Erroneous Fish Records

As with any major river system in North America, several fish species have been reported from the Big Muddy River drainage that remain unsubstantiated by voucher specimens or are considered erroneous. If recognized, they would constitute an extension of the range of a species, an enigmatic zoogeographic occurrence, or an improbable occurrence in a given habitat, or they could represent any of several similar species. Erroneous records are those misidentified as confirmed by examination of extant voucher specimens. Species reported from the drainage that remain unsubstantiated or erroneous include smallmouth bass (*Micropterus dolomieu*[= *M. salmoides*]), rock bass (*Ambloplites rupestris*, probably *L. gulosus*, no voucher; Forbes and Richardson 1908); highfin carpsucker (*Carpiodes velifer*, probably *C. cyprinus*, no voucher;

from Lewis 1955); steelcolor shiner (*Cyprinella whipplei* [= *C. lutrensis*] Lewis and Gunning 1959); mooneye (*Hiodon tergisus*, probably *H. alosoides*, no voucher), black redhorse (*Moxostoma duquesnei*, probably *M. erythrurum*, no voucher; Atwood 1988); river redhorse (*M. carinatum*, probably *M. macrolepidotum*, no voucher; Hite et al. 1991).

Rare and Extirpated Species

Over the last century at least 10 species are indicated as having been extirpated from the Big Muddy River drainage (Table 2), and several others are rare, uncommon, or distributionally problematic in the basin. Three of the 10 species considered as extirpated have received conservation status rankings from the state of Illinois (Illinois Endangered Species Protection Board 1990): alligator gar (*Atractosteus spatula*), cypress minnow (*Hybognathus hayi*), and pallid shiner (*Hybopsis amnis*). None of these species has been reported from the drainage in over 50 years (Table 2). Two other species, the blacktail shiner (*Cyprinella venusta*) and cypress darter (*Etheostoma proeliare*), are on the Illinois watch list (Burr 1991).

The alligator gar, a large-river and lowland species, was reported from the drainage by Forbes and Richardson (1908). The species rarely has been seen anywhere in Illinois since the 1960's (Smith 1979) and has declined precipitously throughout the upper Mississippi River valley (Burr and Page 1986). The cypress minnow was last collected in the drainage from three sites in the Little Muddy River and Beaucoup Creek in 1940 by A. Bauman (Warren and Burr 1989). He took large numbers (>30 specimens) at each site by seining, indicating the species was a relatively common, if somewhat localized (3 of 10 sites), component of the fish fauna. In an effort to rediscover the cypress minnow in the drainage, we resampled Bauman's localities, as well as others, without success, and we consider the species extirpated from the drainage (Warren and Burr 1989). Our sampling of a few remaining riparian wetland habitats (e.g., along Beaucoup Creek) that might potentially support cypress minnows generally yielded a depauperate and tolerant assemblage of fish (e.g., sunfishes, gizzard shad [*Dorosoma cepedianum*], western mosquitofish) and lacked native cyprinids, with the exception of the ubiquitous golden shiner (*Notemigonus crysoleucas*). We suggest that drainage of floodplain wetlands for agriculture was a prime factor in the disappearance of the cypress minnow. Wetlands adjacent to stream channels apparently were used by the species as spawning and nursery areas (Warren and Burr 1989). Agriculture and mining pollution (particularly in the case of Beaucoup Creek) also may be implicated in the extirpation of this once relatively common member of the fauna. The pallid shiner was taken in 1900 and 1940 at three sites, including the Big Muddy River mainstem, Crab Orchard Creek, and the Little Muddy River (Warren and Burr 1988). Despite specific searches for the species, extant populations have not been reported since 1940 (Warren and Burr 1988). The cypress minnow and pallid shiner persist elsewhere in Illinois and nearby states, albeit tenuously in much of the upper Mississippi valley. The alligator gar, however, is poorly represented throughout its range, and there is no evidence of

Table 2. Fish recorded from the Big Muddy River drainage, Illinois, in the period 1892–1992, and now considered extirpated.

Species	Years of collection or probable occurrence			
	1900	1920	1940	1960
Atractosteus spatula	0[a] -------	X[b]		
Hybopsis amnis	0 -------	-------	0	
Hybognathus hayi	X -------	-------	0	
Percopsis omiscomaycus	X -------	-------	0	
Luxilus chrysocephalus	X -------	-------	0	
Cyprinella venusta	X -------	-------	0	
Cycleptus elongatus	0 -------	-------	-------	X
Lota lota	0 -------	-------	-------	X
Anguilla rostrata	0 -------	-------	-------	X
Cyprinella whipplei	X -------	0 -------	-------	0

[a] 0 = occurrences documented by specimens in museums or recorded in the literature and considered valid.
[b] X = probable occurrence of a species at a given time, on the basis of collection or reliable reports in other parts of the drainage.

reproduction anywhere in the upper Mississippi valley.

During the course of status surveys conducted in 1992 (Burr et al. 1992), the blacktail shiner and cypress darter were not found in the Big Muddy River drainage. Both are on the northern edge of their range in Illinois (Smith 1979; Page and Burr 1991), were known from only one or two localities each in the drainage, and were taken originally in small numbers. The cypress darter's habitat now is impounded by Lake Kincaid, and the blacktail shiner probably occurred as a waif in the lower reaches of the mainstem from the Mississippi River. Both species survive elsewhere in southern Illinois and in suitable habitat to the south but can no longer be considered extant in the Big Muddy River drainage.

At least three of the extirpated species, including the American eel (*Anguilla rostrata*), burbot (*Lota lota*), and blue sucker (Table 2), are of some commercial value, and all were present before dam construction and excessive industrial, urban, and agricultural pollution. The striped shiner (*Luxilus chrysocephalus*) and steelcolor shiner (*Cyprinella whipplei*) were known from the lower mainstem. Both have suffered range compression in western Illinois, a pattern attributed to siltation, turbidity, and conversion of perennial to ephemeral streams (Smith 1979), certainly factors operating in the Big Muddy River drainage. Interestingly, Smith (1979) noted that in Illinois the steelcolor shiner was being replaced by the more ecologically tolerant spotfin shiner (*Cyprinella spiloptera*), a species recently recorded for the first time in the Big Muddy River drainage (Table 1).

The former occurrence of the trout-perch (*Percopsis omiscomaycus*) in the Big Muddy River drainage is near the southernmost edge of its range (Gilbert and Lee 1980; Burr et al. 1988). Two collections of the species were made in the 1940's in Kincaid Creek, where the species was apparently common (15 specimens at one site; Burr et al. 1988); now both Kincaid Creek sites are impounded by Lake Kincaid, and no subsequent collections have been made of this species in the drainage. The species is considered extirpated from the drainage.

Based on Table 1, several other species, although not considered extirpated, are rare or at least present problematic distributions in the basin. In 1978, the lake chubsucker was discovered in the basin in a large remnant wetland in the floodplain of the lower river (Burr et al. 1988). Although historical substantiation is lacking, we suggest its restricted distribution in the drainage is a product of the demise of the basin's wetlands. Four other species in the drainage have not been taken for at least 30 years (Table 1), including chestnut lamprey (*Ichthyomyzon castaneus*), silver chub (*Macrhybopsis storeriana*), river carpsucker (*Carpiodes carpio*), and blue catfish (*Ictalurus furcatus*). These species, all characteristic of the Mississippi River, are not rare, sensitive, or extirpated and probably continue to enter the Big Muddy River near the mouth.

On a smaller spatial scale, drainage alteration and watershed deforestation in the Galum Creek system before the 1960's probably contributed to the extirpation of three fishes from that system: Mississippi silvery minnow, emerald shiner (*Notropis atherinoides*), and pugnose minnow (Carney 1990). Five species historically known from Galum Creek were represented only in Little Galum Creek samples in 1989. Little Galum Creek is the only stream in the Galum Creek system that has not been diverted or modified for mining activities (Carney 1990).

Introduced Species

As with most impounded waters in the Midwest, exotic or transplanted sportfishes and forage species have been introduced into all of the moderate to large reservoirs in the drainage. The presence of introduced species raises questions as to their source, their ecological role in the drainage, and their importance to human welfare. The potential ecological effects of introduced and exotic fish on native aquatic communities include habitat alterations (e.g., removal of vegetation, degradation of water quality); introduction of parasites and diseases; trophic alterations (e.g., predation, competition for food); and hybridization, and spatial alterations (e.g., overcrowding; Taylor et al. 1984).

Of the nine introductions in the drainage, eight were apparently intentional, and one, the bighead carp (*Hypophthalmichthys nobilis*), is a recent invader from introductions made elsewhere in the Mississippi River basin. Three of the species are natives of Europe or Asia (grass carp, *Ctenopharyngodon idella*; common carp, *Cyprinus carpio*; bighead carp), one is from western North America (rainbow trout, *Oncorhynchus mykiss*), one originates from the Atlantic Slope (striped bass, *Morone saxatilis*), and the remainder are native to more northern or eastern waters. A plethora of tropical and subtropical aquarium fishes has

been released into the impoundments in the drainage only to perish in the ensuing winter. During the summer of 1992, anglers caught South American pacus (*Colossoma* spp.) from Little Grassy Lake and Southern Illinois University at Carbondale Campus Lake. Rainbow trout have been stocked into Devil's Kitchen and Crab Orchard lakes; they are not known to oversummer in Crab Orchard Lake. Two pikes, *Esox lucius* (northern pike) and *E. masquinongy* (muskellunge), have been transplanted into Kincaid Lake, where the northern pike reproduced the first 2 years. For ostensible vegetation control, the grass carp has been introduced into the Southern Illinois University at Carbondale Campus Lake and numerous farm ponds in the Big Muddy River catchment. On 4 August 1992 one of us (B. M. Burr) documented a single young-of-the-year (27 mm SL) grass carp from the lower mainstem of the river, the only record of natural reproduction of this species in Illinois waters. In the past 2 years, adult bighead carp were taken by anglers from the lowermost mainstem. We recently (4 August 1992), however, documented a single young-of-the-year (24 mm SL) bighead carp from the lower mainstem at Rattlesnake Ferry, again the first confirmation of natural reproduction of this species in the state. We are not certain that either of these species spawned in the Big Muddy River, but plan to conduct additional field work in 1993 in an effort to substantiate reproduction. The common carp was the first and only exotic found in the drainage during the Forbes and Richardson (1908) era, and it remains the most common exotic species. The striped bass has been introduced into Kincaid, Rend, and Crab Orchard lakes as a sportfish and has escaped over the spillways in all three lakes, although nothing is known regarding the survival of the escaped individuals. Humanmade ponds on the Crab Orchard National Wildlife Refuge have received introductions of the pumpkinseed (*Lepomis gibbosus*), and one adult male of unknown origin is documented from Beaucoup Creek. The yellow perch (*Perca flavescens*), transplanted to Crab Orchard and Devil's Kitchen lakes, has reproduced in the latter. The threadfin shad (*Dorosoma petenense*), native to the lower reaches of the drainage, and the inland silverside have been introduced in various impoundments as forage. The inland silverside is dispersing rapidly throughout the lower drainage.

Obviously, some of these introduced species are localized, uncommon, or small and apparently ecologically unimportant. In contrast, many others are voracious predators (e.g., northern pike) on or potential competitors (e.g., recently introduced carps) with native fishes. We do not have enough information to predict the long-term effect of these introductions, but we do note that the ratio of extant native to introduced fish has decreased from 97:1 in 1900 to 9.7:1 today. Given the model provided by the common carp, finding evidence of potential reproduction of bighead carp and grass carp in the drainage is disturbing. If we can confirm that these species are using the river as a spawning and nursery area, we speculate that the mainstem riverine fauna may be given over to these exotics, as it is to some extent now by the common carp.

Sport, Commercial, and Forage Fishes

In 1977, Illinois Department of Conservation fishery biologists, expending at least 60 min of effort per site, sampled five stations on the Big Muddy River with a boat-mounted electrofishing unit. From 1978 to 1986 annual sampling was continued at stations located near the mouth (Rattlesnake Ferry) and middle reaches of the river (near Benton). A comparison of total electrofishing catch at the five 1977 stations indicated greater fish population density near the river's mouth and near the Rend Lake tailwater than elsewhere (Atwood 1988). Over all years (1978–86) sampled, the most abundant fishes listed in decreasing order were common carp, gizzard shad, bigmouth buffalo (*Ictiobus cyprinellus*), bluegill, longear sunfish (*Lepomis megalotis*), largemouth bass (*Micropterus salmoides*), smallmouth buffalo (*Ictiobus bubalus*), freshwater drum (*Aplodinotus grunniens*), channel catfish (*Ictalurus punctatus*), black crappie (*Pomoxis nigromaculatus*), and bowfin (*Amia calva*).

The Quality Sport Fisheries Index (QSFI) also was calculated for the Illinois Department of Conservation samples. The QSFI is derived from sample abundances of a given sportfish weighted by a measure of angler preference (Atwood 1988). According to recent angler preference in southern Illinois, the five most popular sportfishes are catfish, crappie, largemouth bass, white/yellow bass, and sunfish (Atwood 1988). All of the 1977 Big Muddy River stations had either fair or poor QSFI ratings. Over the 10-year monitoring period, the site at Rattlesnake Ferry (near the mouth) had the highest QSFI ratings. Ratings were correlated (Pearson product-moment correlations [r]), in part,

with discharge at the time of sampling (r = .773) and mean annual discharge (r = .741). Low catch rates at some stations probably resulted from high stream temperature, low stream flow, and low dissolved oxygen. Low dissolved oxygen levels could have resulted because of high nutrient loading from substandard sewage treatment facilities at West Frankfort and Herrin (Hite et al. 1991), and also from high organic content of the silt/mud sediments. These factors also may account for the high densities of common carp at some stations.

Composition and relative abundance of species taken during the Illinois Department of Conservation surveys of 1977–86 are similar to those reported by Lewis (1955). He emphasized that most fishing in the river at that time was of a commercial nature. In 1951, only one full-time and 10 part-time commercial fishermen operated on the river. Catches were dominated by common carp and buffalofish (Starrett and Parr 1951). Few commercial operations still exist on the Big Muddy River in large part because of the resultant low standard of living (i.e., low price per kilogram). Today, most commercial fishermen harvest buffalofish (*Ictiobus* spp.), carpsuckers (*Carpiodes* spp.), common carp, and catfishes (channel catfish and flathead catfish, *Pylodictis olivaris*).

Lewis (1955) suggested that the sportfish populations were controlled by extreme fluctuations in water level, lack of spawning sites, and mine-waste pollution. To produce better recreational stream fishing, he urged the elimination of chemical pollution and that more impoundments be built to completely control water-level fluctuations. Ironically, except for Rend Lake, most of the large dams since constructed in the basin have no means of controlling the amount or timing of tailwater release. Garver (1974) described fishing opportunities as abundant in the Big Muddy River, with many desirable species of large size being present, but indicated that fishing pressure was light. Allen and Wayne (1974) described the fishing pressure as heavy at the Rend Lake tailwater, light to moderate in middle downstream sections, and becoming progressively heavier in the lowermost reaches near the river's confluence with the Mississippi. In a survey of stream access, Davin and Sheehan (1991) noted that about one-fourth of all fishing trips in Illinois are made to streams. Weekday pressure accounted for 70% of total fishing pressure (a total of 25,342 h) on the Big Muddy River. At the most commonly used access site on the Big Muddy River (near the mouth), only 15% of the use was for angling purposes during 1989–90. Compared with the nearby Ohio and Kaskaskia rivers, fishing pressure on the Big Muddy River is low. Of the 6,664 h of angling effort recorded by creel clerks during a 20-month period in 1989–90, 52% of that effort was directed to the Ohio River, 34% to the Kaskaskia River, and only 2% to the Big Muddy River (Davin and Sheehan 1991). Poor access to fishing sites is a primary limiting factor. The top four species harvested in southern Illinois during this same period were crappies (combined), bluegill, channel catfish, and largemouth bass.

Index of Biotic Integrity

Hite et al. (1991) sampled seven sites in the drainage with a boat-mounted electrofishing unit in an effort to assess community structure and to evaluate the fish fauna with the Alternate Index of Biotic Integrity (AIBI; Karr et al. 1986). Categories used for the AIBI included (1) species richness and composition, (2) trophic composition, and (3) fish abundance and condition. Hite et al. (1991) collected 947 fish representing 33 species at seven mainstem sites on 15–18 August 1988 (Table 3). Seven species, including shortnose gar (*Lepisosteus platostomus*), gizzard shad, common carp, smallmouth buffalo, channel catfish, bluegill, and freshwater drum, were present at all sites. The common carp was the most abundant species, followed by freshwater drum and bluegill. Centrarchids dominated the 1988 samples, accounting for 31% of all fish collected (mostly bluegill), followed by cyprinids (22.9%), sciaenids (13.6%), clupeids (11.9%), catostomids (8.7%), ictalurids (6.6%), and lepisosteids (3.4%).

Biotic integrity of mainstem fish communities was rated fair based on AIBI values ranging from 31.6 at a station on the lower river (Turkey Bayou) to 38.2 at a station near the mouth (Rattlesnake Ferry) and a more centrally located station (Route 14 West of Benton) out of a total possible AIBI of 51–60. The closest point source pollution to the Turkey Bayou site is 26.4 km upstream at the Murphysboro wastewater treatment plant. This may account, in part, for the low AIBI scores at that site. The AIBI values were generally higher in the upper section (downstream from Rend Lake, southeast of DeSoto, at Blairsville) of the mainstem even though this area has been affected historically by point source pollution.

In the Galum Creek system, Carney (1990) found mean AIBI values to vary from 34.9 to 42.0. Little Galum Creek yielded the highest biotic integrity

Table 3. Summary of 1988 fish community characteristics as used in the Alternate Index of Biotic Integrity (AIBI) at seven sites on the mainstem of the Big Muddy River (Hite et al. 1991). Sampling stations are as follows: N-06 (Rt. 14 W Benton); N-11 (1.1 km W Plumfield); N-17 (Cambria Rd. @ Blairsville); N-16 (3.2 km SE DeSoto); N-12 (Rt. 127 S Murphysboro); N-23 (4.8 km E Johns Spur); N-99 (Rattlesnake Ferry). ND = not determined.

Community categories, metrics, and ratings	Site							
	N-06	N-11	N-17	N-16	N-12	N-23	N-99	Totals
Species richness/composition								
Total species	18	15	20	16	21	16	21	33
Sucker species	2	4	2	4	4	3	4	6
Sunfish species	5	4	7	4	4	2	5	7
Darter species	0	0	0	0	0	0	0	0
Intolerant species	2	3	1	2	2	1	2	4
Trophic composition (%)								
Green sunfish	0	0	1.5	0	0	0	0	0.2
Omnivores	30.5	42.2	39.7	48.1	43.8	36.8	18.7	33.9
Insectivorous cyprinids	6.0	0	2.3	2.8	0	1.1	0.4	2.1
Carnivores	13.0	15.7	10.7	12.3	21.0	24.1	14.5	15.1
Fish abundance/condition								
Proportion of hybrids	0	0	0	0	0	0	0	0
Proportion diseased	ND	ND	ND	ND	ND	ND	ND	ND
Total no. individuals	200	83	131	106	105	87	235	947
Index of Biotic Integrity (AIBI)	38.2	38.2	36.0	36.0	33.8	31.6	38.2	
Stream quality assessment	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Stream classification (BSC)	C	C	C	C	C	C	C	

scores among nine sites sampled in the system in 1989. Except for Little Galum Creek, the other major streams in the Galum Creek system have been diverted and modified as a result of mining activities. The higher AIBI values in the undiverted Little Galum Creek were because of the presence of more native species, particularly darters and suckers.

Fish Contaminants

In 1988, Hite et al. (1991) removed 48 fish representing six species (29 common carp, 1 bigmouth buffalo, 1 flathead catfish, 15 channel catfish, 1 spotted bass (*Micropterus punctulatus*), 1 walleye) from four mainstem sites on the Big Muddy River for contaminant analysis (Table 4). Chlordane, DDT, and PCB's occurred at low levels but attest to the persistence and probably widespread historical use of these compounds in the watershed. Total mercury concentrations were higher in some common carp fillets from river samples than in those from Crab Orchard Lake but did not warrant issuance of a consumption advisory (Hite et al. 1991). The sources of mercury in the drainage are probably from sewage and industrial effluents.

Changes in Fish Assemblages

The 12 collections (Table 1) made in the drainage between 1892 and 1900 contained 45 native species and 1 exotic (Forbes and Richardson 1908). A. C. Bauman made 10 collections in 1939–40 totaling 58 native species and 1 exotic. The surveys of W. M. Lewis from 1950 to 1959 included at least 30 collections containing 64 native species and 1 exotic. P. W. Smith and his colleagues made 65 collections in the drainage from 1963 to 1978 and found 67 native species and 2 introductions. From 1980 to 1992, we made 55 collections in the drainage and recorded 71 native species and 9 introductions. Species richness during each of these periods plotted against the respective number of collections indicates that richness primarily is a function of effort (Fig. 4). Considering sampling techniques, sampling period, effort, and locations sampled, the overall native species composition from several decades of record has changed only moderately in the Big Muddy River drainage (Table 1). Except for some large-river fishes known only from near the mouth of the river, presumed extirpated species, and the more recent fish introductions, Bauman's

Table 4. Concentrations of organochlorine compounds, mercury, and lipids in whole fish samples at selected sites in the Big Muddy River mainstem, 1988 (Hite et al. 1991). Results are as µg/g (parts per million) except as otherwise noted.

Station[a]	Species	Sample type	No. of fish	Length (mm)	Weight (g)	Lipid (%)	Total mercury	Total chlordane	Alpha + gamma chlordane	Dieldrin	Total DDT	Total PCB's	Heptachlor epoxide
N-06	Spotted bass	whole	1	272	300	2.0	0.15	0.09	0.03	0.01[b]	0.04	0.14	0.01[b]
	Flathead catfish	whole	1	458	1090	1.2	0.30	0.07	0.03	0.01[b]	0.02	0.12	0.01[b]
	Bigmouth buffalo	whole	1	437	1180	0.4	0.17	0.02[b]	0.02	0.01[b]	0.03	0.19	0.01[b]
	Common carp	whole	1	465	1340	2.9	0.36	0.07	0.04	0.01[b]	0.02	0.13	0.01[b]
N-11	Common carp	whole	1	487	1420	4.4	0.37	0.33	0.14	0.01	0.09	0.46	0.01[b]
	Common carp	whole	1	455	1150	7.5	0.23	0.53	0.26	0.01[b]	0.12	0.53	0.01
N-12	Walleye	whole	1	467	870	3.1	0.83	0.26	0.11	0.01[b]	0.18	0.89	0.01[b]
	Channel catfish	whole	1	443	710	4.8	0.13	0.17	0.07	0.01	0.15	0.61	0.01[b]
	Common carp	whole	1	411	910	6.3	0.32	0.26	0.11	0.02	0.34	0.78	0.01[b]
N-06	Common carp	fillet	5	398[c]	744[c]	2.5	0.33	0.07	0.05	0.01[b]	0.03	0.29	0.01[b]
N-11	Channel catfish	fillet	4	365[c]	423[c]	0.8	0.45	0.03	0.02[b]	0.01[b]	0.11	0.10[b]	0.01[b]
	Common carp	fillet	5	389[c]	689[c]	1.0	1.05	0.04	0.02[b]	0.01[b]	0.02	0.10[b]	0.01[b]
	Common carp	fillet	5	381[c]	705[c]	3.8	0.89	0.21	0.11	0.01	0.05	0.22	0.01[b]
N-12	Channel catfish	fillet	5	396[c]	554[c]	1.7	0.36	0.03	0.02[b]	0.01[b]	0.03	0.10	0.01[b]
	Common carp	fillet	5	455[c]	1327[c]	1.8	0.80	0.11	0.05	0.01[b]	0.07	0.13	0.01[b]
N-99	Channel catfish	fillet	5	374[c]	499[c]	1.6	0.45	0.05	0.03	0.01[b]	0.04	0.10	0.01[b]
	Common carp	fillet	5	400[c]	822[c]	1.6	0.85	0.02	0.02[b]	0.01[b]	0.03	0.10[b]	0.01[b]

[a] Sample sites are identified in Table 3.
[b] Less than detection limit.
[c] Average length and weight of multiple fish.

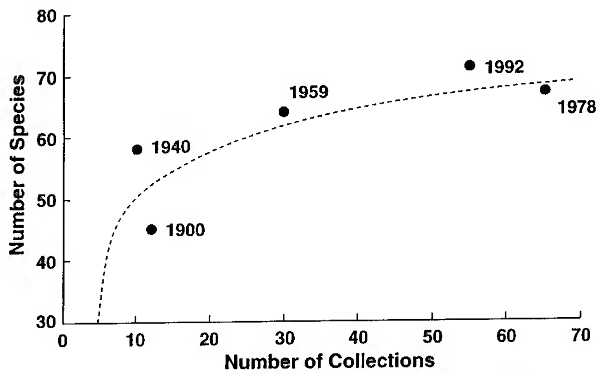

Fig. 4. Relation between fish species diversity and sampling effort (number of collections) over time in the Big Muddy River drainage. Years correspond to the five eras as discussed in the text: 1900 (Forbes and Richardson); 1940 (A. C. Bauman); 1959 (W. M. Lewis, Sr.); 1978 (P. W. Smith); and 1992 (B. M. Burr). The line was fitted by visual inspection.

samples from 1939–40 seem to be representative of the present known native fish fauna. This interpretation of the data, however, may be misleading and may overlook some important subtleties. For instance, could Bauman's results of 58 species in 10 collections be repeated today? We suspect not.

Changes in the fauna are not as readily apparent in species richness as in assemblage structure. Examination of Bauman's collection records from tributaries and comparison with other collections from the same localities made at later dates (Table 5) demonstrate rather striking changes in cyprinid fish assemblages over time. For example, one site on the Little Muddy River near Tamaroa has been sampled for maximum species diversity and abundance on four different occasions (Table 5). Three species (cypress minnow, pallid shiner, pugnose minnow) taken in Bauman's samples have not been collected at this site in over 50 years. Interestingly, Bauman did not collect any of the tolerant cyprinids that are now common at this site and elsewhere in the drainage. Even in 1963, the now abundant red shiner was not present at this site. The original cyprinid assemblage at the Little Muddy River site and elsewhere in the basin appears to have been replaced by aggressive minnows (e.g., red shiner, common carp) that are either tolerant of a wide range of chemical and physical parameters (i.e., dissolved oxygen, temperature, turbidity, siltation) or spawn readily in disturbed habitats (e.g., ribbon shiner [*Lythrurus fumeus*], redfin shiner). Considering the dramatic physical and chemical alterations that have occurred in the drainage for over 100 years, the permanence of the bulk of the fauna is a testament to the ability of fish communities to respond and persist under a variety of stochastic processes.

Discussion

As a matter of historical record, we have emphasized the many changes that have taken place in a century of use by humans living, working, and recreating in the Big Muddy River drainage. From written history, the river always has displayed lowland characteristics, and because of its muddy banks, predominantly silt substrate, and sluggish flow has never been particularly popular with anglers, boaters, and other potential users. The drainage also has been as abused environmentally as any in the Midwest; conversely, portions of the drainage are as scenic (e.g., Little Grand Canyon, Giant City State Park) and heavily used for a variety of purposes as any in Illinois. Except for the heavy angling use on reservoirs, the fishery resources have been underused historically in the river. Several small upland streams in the basin contain significant populations of spotted bass, and the mainstem maintains large populations of important commercial and sport fishes and smaller populations of desirable sport fishes, all of which have received little fishing pressure, as judged from surrounding areas.

Illinois is a model state in view of its excellent database documenting changes in fish distributions over time. Although we have learned a great deal about the effects of human activities on the aquatic environment in the Big Muddy River, we must continue to conduct basic survey work on its fish populations and to document long-term changes in the fauna. Because fishes are sensitive indicators of environmental quality, continued collection of data will aid in monitoring a variety of stream-quality parameters and assist public agencies in identifying quality habitats in need of protection. Many of the smaller streams in the Big Muddy watershed have never been sampled adequately for fishes or had their environments assessed in any modern sense.

Because of the number of species extirpated or endangered in the Big Muddy River drainage, we need to establish a monitoring program and status surveys of species on the watch list. The most effective course of action might be to allocate funds and efforts on species that may be realistically

Table 5. Changes in the minnow (*Cyprinidae*) fauna over time as recorded from Little Muddy River, 8 km east Tamaroa, Jefferson County, Illinois. Data are number of specimens collected.

Species	Bauman 1940	Smith et al. 1963	Burr & Mayden 1979	Burr & Warren 1988
Hybognathus hayi	37			
Hybopsis amnis	2			
Opsopoeodus emiliae	3			
Notemigonus crysoleucas	62	4		
Semotilus atromaculatus	1	2		
Lythrurus fumeus		10	5	10
L. umbratilis		6	35	2
Pimephales notatus		11	6	41
Cyprinella lutrensis			17	57
Cyprinus carpio				4

recoverable, rather than expending efforts on species already nearing extirpation in the basin.

Over the past several years, we have come to recognize that single-species fish management, developed largely to placate the perceived needs of predominant users (i.e., anglers), often results in overly expensive programs emphasizing simplified ecological principles and low biological diversity. Future management practices should strongly consider a fish-community approach that encompasses an entire basin and its fauna, not just the artificial milieu of reservoirs. In view of this, more funding is needed for studies on basic fish biology, especially nonsport fishes, emphasizing reproductive biology, trophic ecology, predator-prey interactions, and parasites and diseases.

Game and sportfishes have been stocked in Big Muddy River reservoirs for years. Observations by several biologists have confirmed that many of these species disperse over the dams, and their presence has been confirmed in the tributaries and mainstem. The ecological effects on stream fishes never subjected to such major predators as striped bass and muskellunge are unknown but are probably detrimental. In addition, the long-term ecological and economic effects of the recently introduced Eurasian carps (i.e., grass and bighead carps), both of which are documented here for the first time to be either reproducing in the river or using it as a nursery area, are again unknown. We strongly recommend discontinuance of stocking of nonnative sportfishes and nonnative forage species until their effects on the river fauna can be monitored and assessed.

An education program for potential users of the Big Muddy River could be developed to convince anglers to seek out fish in the drainage because its "muddy" condition is natural. In addition, resource managers could control harvest of sportfishes to create a trophy fishery for catfishes. This might attract anglers and thus build a base of concerned users.

While environmental problems of nearly every conceivable kind have plagued many of the tributaries and parts of the mainstem for decades, recent changes in legislation and regulation regarding wastewater treatment, strip-mine reclamation, and water quality standards have greatly improved the condition of the river and presumably the fish populations. Much of the previous pollution that continued unabated for years has now been either halted, or plans for improvement are being implemented. These improvements probably will not allow recovery of already extirpated species but may allow rare species to survive in the habitat available.

The drainage of wetlands adjacent to the river has historically eliminated spawning and nursery areas for some species and year-round habitat for others. We recommend that wetland drainage be halted on any scale until an ecological plan for the entire drainage can be formulated. Moreover, we advocate recovery of lost riparian wetlands and the development of a land acquisition program to achieve more wetlands in the watershed. Likewise, reservoir construction and stream channelization also should be discontinued because of the destructive effects these practices have on large expanses of stream habitat.

Some practical and economically feasible suggestions (Davin and Sheehan 1992) to increase use of the Big Muddy River include (1) improving stream access sites (e.g., clean-up silt loads at boat ramps), (2) providing more support facilities near

access sites, and (3) adding additional access sites to provide opportunity for additional use of the resources. In addition, we recommend establishment of permanent mainstem and tributary sampling stations where annual or biannual standard (i.e., CPUE) monitoring can be conducted.

There is still a need to identify stream segments of exceptional quality in the Big Muddy River drainage that warrant special consideration for protection. Continued vigorous reclamation of abandoned mine lands and treatment of acid mine drainage is imperative. Finally, we must focus greater emphasis on the importance of valuable stream resources and an awareness of where these resources exist.

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Environmental Changes in the Kaskaskia River Basin

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Abstract. The Kaskaskia River originates in east-central Illinois and flows southwesterly for about 475 km, where it joins the Mississippi River 11 km above Chester, Illinois. The river and its tributaries have been subjected to numerous physical modifications, including drainage and levee projects, dredging and straightening of tributary streams, channelization of the lower 80 km for navigation, and construction of two mainstem flood control and water supply reservoirs. The diversity of the river's fish and mussel population is evident by the 113 native and 12 nonnative fish and 42 mussel species collected since the early 1900's. We present information on the fish present, sport and commercial fishing, mussels and mussel harvest, benthos, plankton, and periphyton. Additional information is provided relative to the river's geology, hydrology, and water quality before and after physical modifications.

The human-induced changes associated with development of the Kaskaskia River may be seen in most midwestern basins. The river has been channelized, impounded, and polluted. In this paper, we review events that have affected the river since the first white men settled in the basin and proceeded to modify the river's drainage, water quality, and aquatic communities. We conclude with suggestions for reasonable use and management of the present water resources.

The Basin

The Kaskaskia River basin has an area of 15,126 km^2 extending from just west of Champaign, Illinois, southwestward 299 km to the Mississippi River in Randolph County (Fig. 1). Its watershed averages 53 km wide, with an extreme width of 89 km. The basin is underlain with rock of the Pennsylvanian and Mississippian periods and was entirely covered by the Illinoisan glacier and, more recently, the 161 km above Shelbyville, by the Wisconsinan glacier. The soils originating from the glacial till and loess are fertile in the upper one-third of the basin, where they are predominantly brown silt loam and black clay loam, with a rather loosely packed subsoil. In the lower two-thirds of the basin, which was covered with Illinoisan drift, the soils consist of loams, silts, and loess, with a compact clay subsoil.

At the time of the first European settlement, the fertile upper one-third of the basin was dominated by tall-grass prairie that included large areas of marsh in the extreme upper portion. Much of the remaining part of the basin was forested with oaks,

[1] Retired.

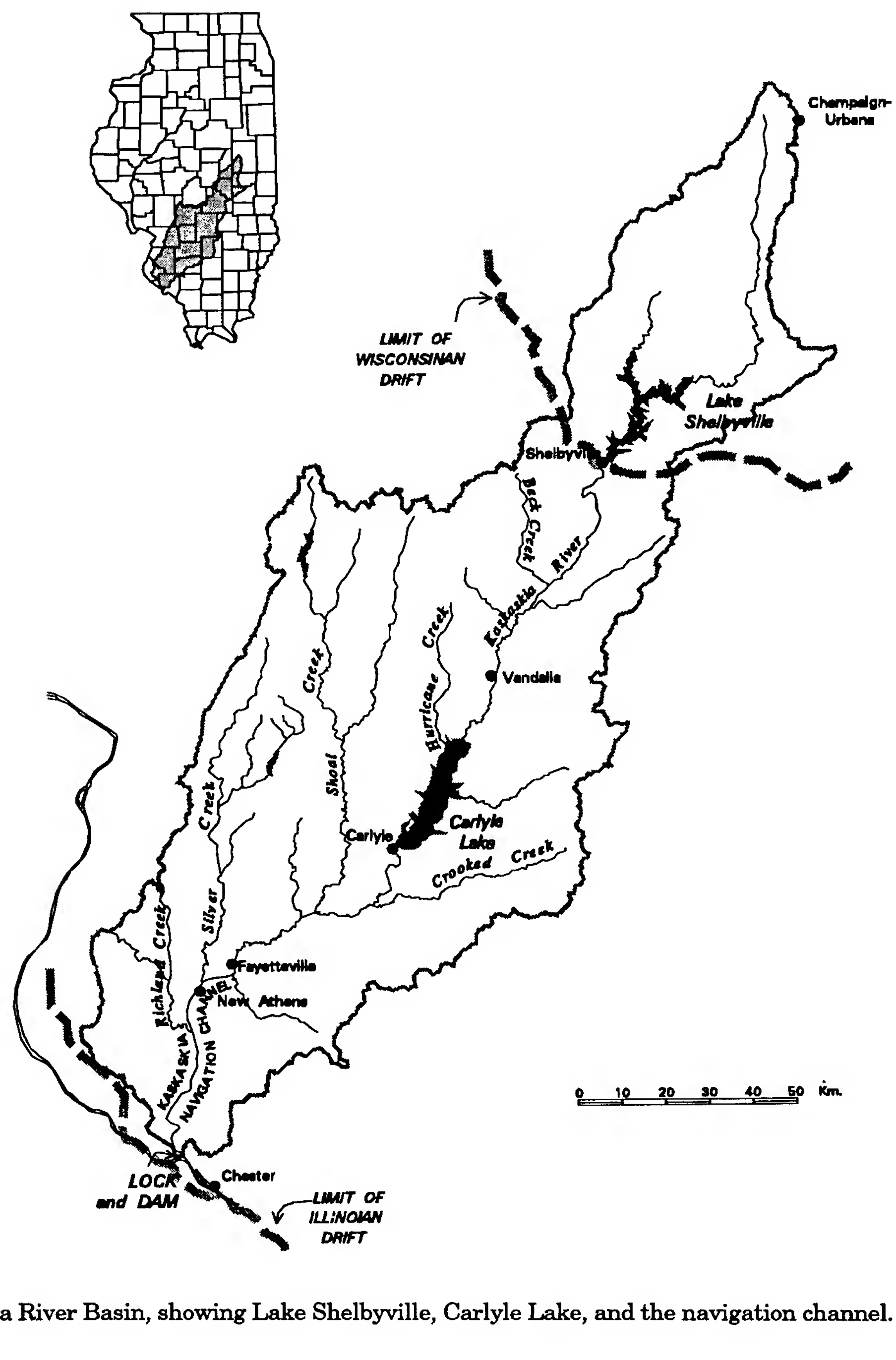

Fig. 1. Kaskaskia River Basin, showing Lake Shelbyville, Carlyle Lake, and the navigation channel.

hickories, elms, and soft maples. The tall-grass prairie with its marshes was drained and most of the forest removed as agriculture became the major industry of the basin.

The River, Tributaries, and Floodplain Pools

The Kaskaskia River originates on the south slope of the Champaign moraine 10 km west of Champaign, Illinois. From here the river flows southwestward for 523 km (length before channelization and impoundment) to enter the Mississippi River 11 km above the town of Chester, approximately midway along the Mississippi River between the mouths of the Missouri and Ohio rivers. If we measure the river from its official source, at an elevation of 259 m, it falls about 152 m before it enters the Mississippi at an elevation of 107 m above sea level. In its first 24 km, as it comes off the Champaign moraine, it falls about 55 m, or 4 m/km (Fig. 2). Disregarding the reach where the stream frequently has intermittent flow, the gradient from about 201 m elevation to its confluence with the Mississippi has a rather steady fall of 98 m, or about 0.2 m/km. The gradient is steeper only where the river crosses the Cerro Gordo and Shelbyville moraines between Sullivan and Shelbyville. These dimensions of basin, river, and gradient have been changed by shortening the river with construction of two large mainstem reservoirs and channelizing the lower reach for navigation.

The distribution of bottom materials in the river has been determined by the underlying bedrock, glacial history, stream gradient, and more recently, by uses and modifications of the basin and its drainage system. Figure 3 shows the mainstream bottom materials before disruption by the reservoirs and channelization.

Discharge records from 1908 to 1947 show maximum and minimum recorded discharge at four stations along the river before impoundment (Table 1). In only three of these years did the river not exceed channel capacity at Vandalia, representing one-third of the basin. Floods occurred most frequently in April (29 times during the 39 years of record) and least frequently in August (1 time). Measurements at Carlyle and Shelbyville expressed as percent duration (Figs. 4 and 5) show the annual discharge before and after the stream was impounded. The Shelbyville gauge measures discharge from the upper 4,025 km^2 or approximately one-sixth of the basin; the Carlyle gauge measures discharge from 7,042 km^2 or roughly one-half of the basin. (These more recent area dimensions are larger than those given in tables 1 and 2 because of more precise distinction of drainage boundaries in the flat, upper basin.) These two figures also show flow durations during a wet year and a dry year after construction of the two reservoirs. The most obvious influence of the reservoirs is early stabilization of low discharge during the dry years.

The mainstem of the Kaskaskia River receives 27 tributaries with drainages larger than 65 km^2 and 9 with drainages more than 518 km^2. Shoal Creek, Silver Creek, and Crooked Creek, with drainage areas of 1,277, 2,473, and 1,222 km^2, respectively, compose one-third of the drainage basin. Most of the tributaries have good water quality and support a diverse fish fauna. Several streams in the southwest portion of the basin, however, are badly degraded from surface mining of coal and poorly treated municipal wastes.

Floodplain pools and wetlands are important parts of the basin's aquatic ecosystem, processing nutrients, providing food and spawning areas for river fish, contributing young fish back to the river, and providing angling for a wide variety of fish. Some pools may be temporary, but all are connected to the main river at some time during most years. Along low-gradient streams, such pools may be formed from (1) old river meanders that are cut off as the stream changes course during geologic aging of the floodplain, (2) depressions in the floodplain scoured out during periods of high water, (3) depressions in the floodplain isolated by natural or artificial terrace building, and (4) temporary or forming stream meanders (Larimore et al. 1973).

Floodplain pools as aquatic habitats in the Kaskaskia Basin are directly influenced by the amount of shade (overhead canopy), development of surface mats of aquatic vegetation, amount of flushing by the river during periods of high water, and degree of permanency, that is, whether they dry up or exist with water throughout the year. Two of these influences, the canopy and surface mats, directly inhibit penetration of light and indirectly inhibit primary production of aquatic plants. The amount of flushing during periods of high water influences not only the development and existence of surface mats and the deposition of silt but also the ingress or egress of aquatic organisms.

Many floodplain pools and wetlands have been drained for agricultural purposes, while others

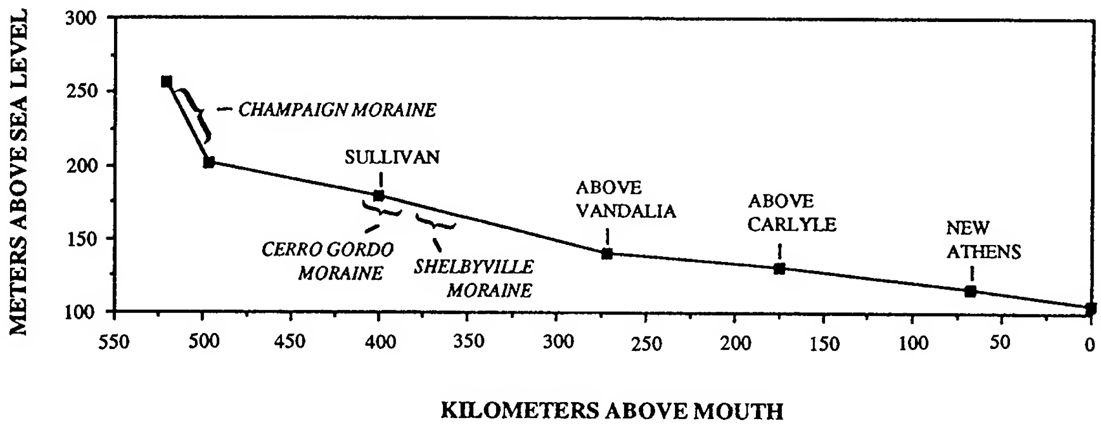

Fig. 2. Gradient profile of the Kaskaskia River before impoundment or canalization (modified from Luce 1933).

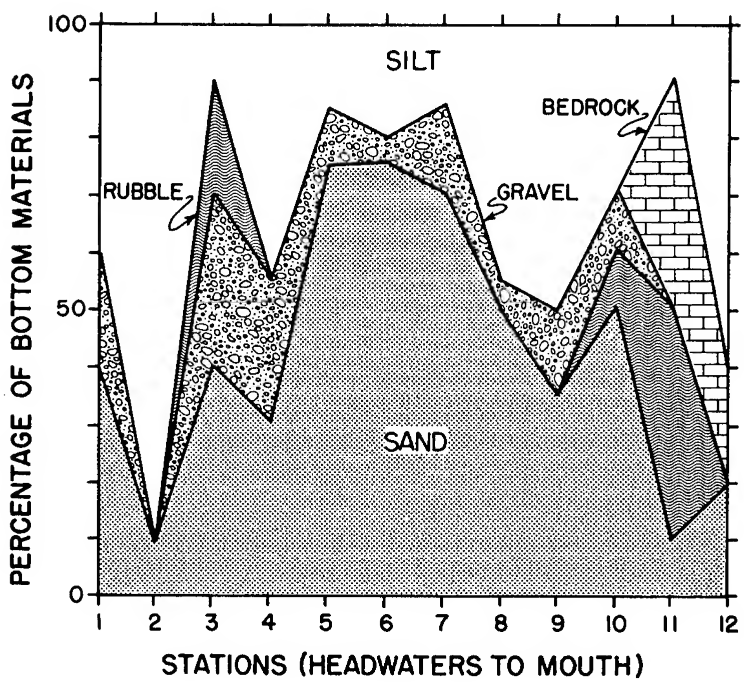

Fig. 3. Percent of bottom materials from headwaters to the mouth of the Kaskaskia River (from Thomas 1970).

Table 1. Extreme discharges, Kaskaskia River, 1908–48. Records from U.S. Geological Survey summarized in U.S. Department of Interior (1954).

Station	Drainage area (km^2)	Maximum recorded discharge (sec. ft.)	Date	Minimum recorded discharge (sec. ft.)	Date
New Athens	13,520	83,000	23 May 1943	61.0	26 September 1936
Carlyle	6,941	54,400	21 May 1943	22.0	19 September 1940
Vandalia	5,128	52,200	17 May 1943	3.5	22 August 1911
Shelbyville	2,668	25,000	19 May 1943	0.6	8 November 1940

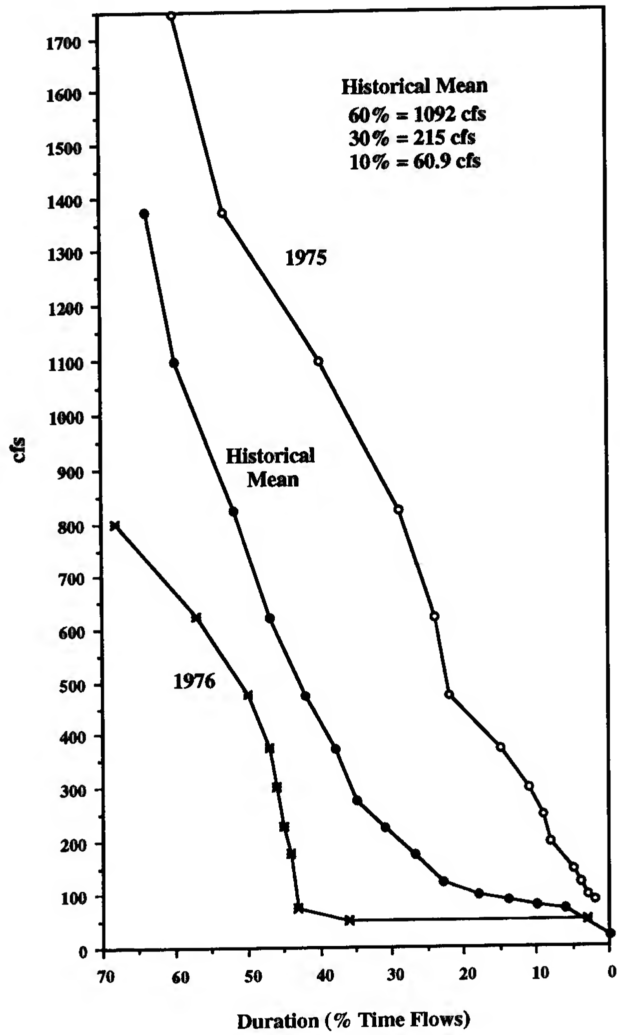

Fig. 4. Duration of flow in the Kaskaskia River at Carlyle from 1909 to 1966, before impoundment, and for 1975 (a wet year) and 1976 (a dry year), after impoundment.

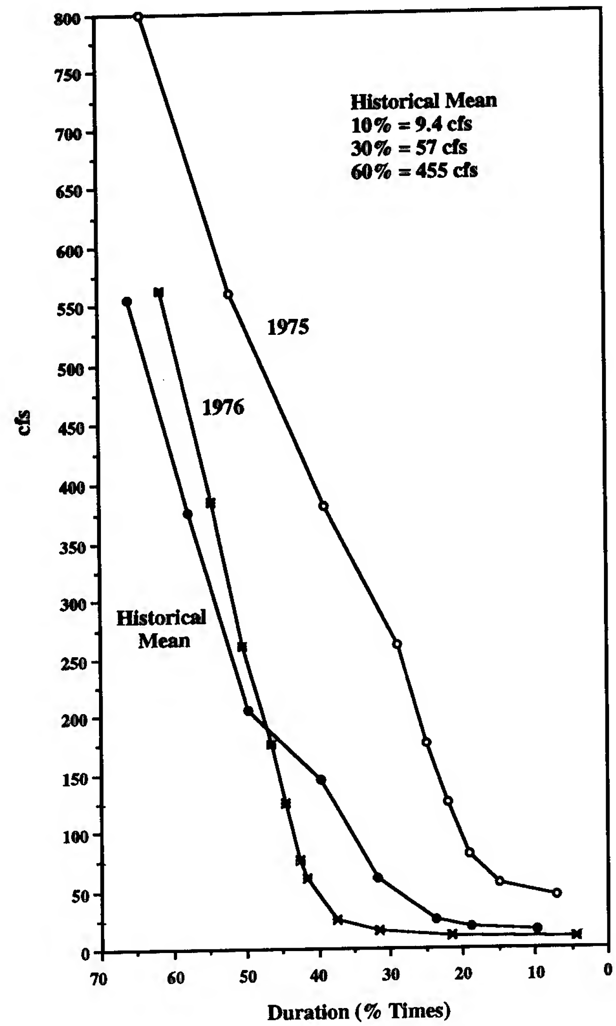

Fig. 5. Duration of flow in the Kaskaskia River at Shelbyville from 1909 to 1966, before impoundment, and for 1975 (a wet year) and 1976 (a dry year), after impoundment

have been biologically degraded through isolation from the flushing floods of the river. A 1992 survey of Illinois wetlands (Suloway et al. 1992) found less than 6% of the Kaskaskia basin to be in wetlands. If one ignores the deepwater habitats, which includes some waters over 2 m deep in reservoirs, the remaining shallow wetlands amount to about 4.3%. Subtracting those shallow wetlands that are artificial (created by levees) leaves about 3.6% of the basin in natural shallow wetlands. The upper basin is 1.4% shallow wetlands, even though much of this area was originally in tall-grass prairie marsh.

Early Use of the River

The village of Kaskaskia was established as a trading post near the mouth of the Kaskaskia River in the late 1600's, when the first white man settled in the Kaskaskia Basin in 1699 (Pease 1937). During the following years sporadic movements of immigrants arrived, some only to stay a short period as the control of the region changed from French to British to the early American colonists. Diseases were viewed as a normal part of life, so ordinary that few records exist. General historic accounts indicate that malaria, typhoid

fever, diarrhea, cholera, smallpox, diphtheria, and tuberculosis were common in the Kaskaskia basin and may have killed many more pioneers than did Indians, wild animals, and economic hardships (Richardson 1937). These frontiersmen used the Kaskaskia River for transportation from the Mississippi waterway toward the interior of what is now Illinois, with the Kaskaskia village being the center of trade and communication. The early settlers fished the river and the many floodplain pools, hunted the lowland woods, and farmed along a few of the major tributaries, but in general, did not attempt to farm the main floodplain of the Kaskaskia.

Small steamboats moved up the river for trade and transportation until 1881, when the Mississippi River broke through a neck of land in the bend of the Mississippi 3 km above the old town of Kaskaskia and permitted the Mississippi to flow into the lower reaches of the Kaskaskia River. This change caused sand and soft muds to accumulate around the mouth of the stream, restricting further boat passage.

By 1880, there were about 200,000 people in the Kaskaskia valley; it was from this time forth that the economic interests of the settlers had an enormous effect on the Kaskaskia basin, the river, and its major tributaries.

Physical Modifications

Draining and Channelizing

The Illinois Farm Drainage Act of 1879 permitted formation of drainage districts and enabled farmers to participate in the installation of drainage systems to serve large areas. Drainage proceeded rapidly during the following decades, especially in the upper reaches of the Kaskaskia River and several of the major tributaries. Channel clearing and straightening and ditching of poorly drained areas lowered the water table and hastened the runoff of water. Flood peaks became higher, and low flows became lower. Many aquatic habitats, marsh areas, and floodplain pools that were important breeding and feeding grounds for fish and waterfowl were eliminated. Stream habitats were destroyed where areas were dredged and drastically modified elsewhere by changes in the water regime (Larimore and Smith 1963).

Canalizing

The War Department, in its statement to Congress with the Rivers and Harbors Act of 3 July 1930, concluded that the development of river navigation in the basin was not warranted by the volume of agriculture and industrial products of the region. This view was restated in 1938 (Illinois State Planning Commission 1938).

In June 1966, however, work had begun to prepare the Kaskaskia River below Fayetteville for barge traffic. Justification for this drastic alteration of the river was to move coal from the New Athens area to St. Louis by barge instead of on the shorter railroad route already being used. The project was completed in 1973 and resulted in shortening the Kaskaskia River between its mouth and Fayetteville from 84 to 58 km. Meanders were eliminated, much of the channel was excavated, the banks were piled with spoil, and the flow and water level were controlled by a lock and dam near the mouth of the river.

Impounding— Carlyle Reservoir

The comprehensive plan of 1938 pointed out many possible reservoir sites, including a large upstream impoundment at Shelbyville, but did not suggest a mainstem impoundment at Carlyle. During the 1950's, however, under strong political pressure, the U.S. Army Corps of Engineers agreed to build a dam at Carlyle. The Flood Control Act of 1958 authorized the establishment of Carlyle Dam and Reservoir to provide flood control and water-quality control, low-flow augmentation, navigation, industrial and domestic water supply, and recreation. By 1965, the dam was essentially complete, eventually impounding almost 9,948 ha of water (Table 2). Although planned to protect nearly 22,258 ha of land, many of these areas were flooded during the first wet periods, when water releases exceeded downstream channel capacity. Subsequently, flooding was reduced through modified releases from Carlyle Lake. Other problems that have arisen include the following: (1) flow augmentation for navigation through the downstream canal has not been adequate during dry seasons; (2) the shallow rectangular reservoir with a long fetch and low banks has resulted in severe bank erosion, high turbidity, and dangerous winds; and (3) siltation is threatening the life of the shallow reservoir.

Table 2. Design data for Carlyle Lake and Lake Shelbyville (modified from U.S. Army Corps of Engineers 1964).

Item	Carlyle Lake	Lake Shelbyville
Drainage area above dam (km^2)	6,941	2,668
Top of dead storage pool		
Elevation (m msl)	130.8	174.7
Area (ha)	2,711	1,214
Storage (m^3)	6.1×10^7	3.7×10^7
Top of joint-use pool		
Elevation (m msl)	135.6	182.8
Area (ha)	9,948	4,492
Storage (m^3)	3.4×10^8	2.5×10^8
Top of flood control pool		
Elevation (m msl)	141.0	191.0
Area (ha)	23,634	10,239
Storage (m^3)	1.2×10^9	8.4×10^8
Minimum release (cfs)	50	10
Nondamaging flow release (cfs)	4,000	1,800
Maximum allowable release for lake level below top of flood pool (cfs)	10,000	4,500

Impounding—Shelbyville Reservoir

Construction of a dam at Shelbyville was authorized in 1958 and completed in 1970. The project was designed to provide flood control for 23,877 ha of land, water supply, recreation,and fish and wildlife benefits, and to augment the supply of water for downstream navigation. The reservoir (Table 2) has a watershed of 2,668 km^2, a surface area of 4,492 ha, and a wooded shoreline of 277 km.

Although impounding the river at Shelbyville destroyed many miles of the most attractive portion of the Kaskaskia River, with its populations of smallmouth bass and rock bass, Lake Shelbyville has not suffered the serious physical problems experienced at Carlyle. The deeper water of Shelbyville, more protected by high banks and irregular shoreline, has provided good boating and fishing. Compared with Carlyle Lake, siltation is not apparent, and the banks remain stable except for the steep banks and exposed points.

General Influences of Modifications

The disappointing flood protection and economic growth provided by the two large reservoirs have not justified displacement of families and farms, reduction in tax base, and disruption of local services (Dwyer and Espeseth 1977). Expected industrial development and population increase have not materialized.

The channelized river between Fayetteville and New Athens has not been used for navigation and thus has served no purpose but to destroy a productive stretch of water. The costs of constructing and maintaining the used portion of the navigation project (below New Athens) have not been justified by the slightly lower costs of moving high-sulfur coal down the river.

Many drainage projects and small impoundments have affected several of the Kaskaskia River tributaries, and the mainstem has been modified by levees and channel-clearing work in the Vandalia area and between Carlyle and Fayetteville.

These developments have eliminated or drastically modified aquatic habitats in the Kaskaskia basin. Some of the influences have been immediate; others have been subtle and chronic. Whatever the influences, their impact on existing aquatic habitats and aquatic communities must be understood to mitigate the detrimental effects and optimize the potential for good effects.

Water Quality

Luce (1933) considered the Kaskaskia River one of the cleanest Illinois streams in 1929. He pointed out, however, that during certain periods

and at certain places pollution existed to the point of killing fish or forcing them to abandon affected reaches. In 1937, of the 103 incorporated municipalities in the Kaskaskia basin, only 19 had public sewer systems, and of the 19 only 7, or 23%, provided proper treatment of their waste (Klassen 1937). At that time, pollution from mine wastes was considered a serious problem (Illinois Department of Mines and Minerals 1937). There were 38 active and 8 inactive shipping mines and 64 load mines, most of which produced acid water in considerable quantities, sufficient, when it reached the streams, to become destructive to aquatic life. Most of the communities in the Kaskaskia basin have made great progress during the past 50 years in the treatment of their domestic waste, most of which now receives primary and secondary treatment. There is relatively little industrial or mining pollution except in the southern part of the basin.

During the summers of 1982 and 1983, the Illinois Environmental Protection Agency and the Illinois Department of Conservation surveyed water quality at 140 sites in the Kaskaskia River basin (Kelly et al. 1989). In stream sediments, they found elevated cadmium, chromium, copper, lead, and mercury at various sites mostly associated with industries in the southwestern part of the basin. Scattered throughout the basin were sites with high concentrations of organochlorine compounds (chlordane, heptachlor, and dieldrin) in the sediments. They found various constituents highly elevated in the waters downstream of municipal wastewater treatment plants at only five towns, these being in the southwestern part of the basin. Considering that the human population in the basin doubled between 1937 and 1976, this small number of inadequate municipal systems represents a real improvement in waste treatment during the past 5 decades.

The enormous increase in the use of commercial fertilizers during the past 50 years has produced a new threat to the water quality of the Kaskaskia River, especially in areas of intensive grain farming. Harmeson, Sollo, and Larson (1971) estimated that 88% of the nitrates in the headwaters of the Kaskaskia River originated from tilled soils and inorganic chemical fertilizers. Kelly et al. (1989) looked at data for 1981–86 from the Ambient Water Quality Monitoring Network and found 90% of 1,153 basin samples contained total phosphorus above the standard set for streams immediately above reservoirs. High phosphorus and nitrate–nitrite levels in the intensely farmed area above Lake Shelbyville were attributed to nonpoint agricultural sources.

Although commercial fertilizers have increased the load of nitrogen and phosphorous in the surface waters of the basin, there have been no catastrophic effects on the aquatic community. However, these same elements, especially nitrogen as anhydrous ammonia or phosphorous as phosphoric acid, have caused fish kills when accidentally or carelessly introduced into surface waters in concentrated amounts. Other sources of agricultural pollution include drainage from dairy farms, especially in that portion of the basin near the St. Louis metropolitan area, or runoff from cattle and hog feed lots.

The major pollution of the Kaskaskia River has undoubtedly been sedimentation brought on by greater production of row crops and removal of streamside timber and vegetation. In some stretches of the river, production of fish and invertebrates has been diminished by the filling of the deeper pools or covering of spawning and feeding areas. Sediments bearing agricultural chemicals have also contributed to the pollution load in the system.

Plankton, Periphyton, and Macrophytes

During the summer of 1929, Luce (1933) took plankton samples at each river station he visited but found a sparse and unimpressive population. More intensive studies of zooplankton and phytoplankton in the upper Kaskaskia River and adjacent floodplain pools were made by Doyle (1971) and Larimore et al. (1973). These studies revealed that the river proper contained very little zooplankton but that the adjacent floodplain pools had a well-developed population composed of crustaceans and rotifers. The zooplankton population composition and abundance in the floodplain pools seemed to be influenced by the amount of vegetative surface cover (*Lemna, Wolffia,* etc.) and by predation coming from other plankters and from associated fish populations. Phytoplankton followed a successional development from river to open floodplain pool to marsh pool. The total phytoplankton population increased fivefold from the Kaskaskia River to the open pool, even though species composition remained similar, being predominantly diatoms, with euglenoids and green algae common. From the open pool to the marsh

pool the total phytoplankton decreased rapidly as surface mats developed and rooted vegetation became more abundant. The phytoplankton population became dominated by euglenoids able to survive under progressively more eutrophic conditions. In another study, a great abundance (up to 30 mg/m^3) of microcrustacea was being discharged from Lake Carlyle a year after the river was impounded (Larimore 1972).

Periphyton has been well studied in the upper Kaskaskia River but not in the lower river. The invertebrates associated with the periphyton communities were found to colonize woody substrates. Initial colonization was rapid, followed by 2 weeks of slow growth, a rapid increase during the next 2 weeks, and then leveling off at 1,650 mg/m^2 during the final week (Nilsen 1968; Nilsen and Larimore 1973). Woody substrates as sources of periphyton and fish food were found to be especially important in areas of the river with shifting sand bottoms that supported a very sparse benthic population.

In a tributary of the upper river, periphyton assimilated two to three times more dissolved organic matter at stations influenced by municipal wastewater than at stations not influenced by the effluent (Brigham and Larimore 1972). Periphyton was very sensitive to changes in the aquatic environment. Rate of accrual on glass slides, community composition, standing crop, production rate, and efficiency of production were all considered in an intensive investigation in the upper river and related to various physical, chemical, and biological parameters, such as water depth, light penetration, current velocity, and primary consumers (Doyle 1971; Larimore et al. 1973). In general, the study showed the importance of the periphyton communities in the primary and secondary production of floodplain pools and the river, especially in areas of shifting sand. Primary production in the river itself, where phytoplankton is sparse, is essentially limited to the periphyton.

Submersed aquatic vegetation in the Kaskaskia system is limited to smaller headwater streams, backwaters, and floodplain pools (Table 3). Development of submersed vegetation in the main river is restricted by high turbidity, which limits light penetration, and by drastically fluctuating water levels. In floodplain pools, submersed plants are more inhibited by dense, shading canopy or by blanketing mats of surface plants in pools that are no longer seasonally flushed by the river. Emergent plants and those that inhabit gravel bars, mud flats, and most shorelines form the most diverse communities of aquatic plants. Composition of these communities changes according to frequent changes in water depth and velocities.

Assemblages of floating plants that form surface mats on quiet waters (*Lemna, Wolffia*, etc.) are, as just mentioned, restricted to backwaters and floodplain pools. Other plants with floating leaves but with roots in the substrate (e.g., *Nuphar*) are restricted to slow-moving or quiet waters, at least in the Kaskaskia system. These plants provide substrates for fish food organisms, but may so completely cover the water surface as to inhibit phytoplankton and periphyton production.

Table 3. Some representative aquatic vascular plants in tributaries, pools, and the mainstem of the lower Kaskaskia River (from Larimore 1978).

	Submersed	Emersed[a]	Floating
Tributaries	*Anacharis* *Potamogeton*	*Justicia* *Sagittaria*	
Floodplain pools and backwaters	*Ceratophyllum* *Myriophyllum* *Potamogeton*	*Sagittaria* *Hibiscus* *Alisma* *Bidens* *Typha*	*Spirodella* *Lemna* *Wolffia* *Nuphar* *Ludwigia*
Main river		*Hibiscus* *Sagittaria* *Typha*	

[a] Includes several semi-terrestrial species that grow on stream banks and bars that are often under water.

Macroinvertebrates

Before impoundments and canalization, the distribution of macroinvertebrates was largely determined by bottom materials. In the upper reaches where the river cuts through the Shelbyville and Cerro Gordo moraines (Fig. 1), the course sand, gravel, and rubble supported diverse populations of insects, with caddis fly larvae composing up to 73% of the numbers and 92% of the weight of the benthic standing crop (Fishman 1968). In the low gradient downstream areas with sand–silt bottoms the benthos was less diverse and was dominated by worms, midges, and mayflies. These organisms became even more dominant after the river was impounded and canalized. The quiet water and soft bottoms of semi-isolated oxbows and floodplain pools support similar benthic populations (Larimore et al. 1973), but here they are severely limited by surface mats, dense stands of aquatic vegetation, accumulations of detritus, oxygen exhaustion, flocculent bottom materials, and drying up of the water area. Flushing by floodwaters reduces the accumulation of detritus, promotes benthic production, and moves these fish foods into the river system.

The Kaskaskia River, even with its drastically fluctuating turbidity, temperature, and volume, experiences definite daily and annual cycles of drifting macroinvertebrates (Larimore 1972). The usual daily cycle consists of an enormous increase in abundance of drifting organisms as light intensity diminishes in the evening and a decline in abundance as light intensity increases in the early morning. A seasonal cycle follows the pattern of increase during spring and into summer, with a gradual decline in late fall to low numbers of drifting organisms during winter months.

Drifting organisms compose a substantial part of the food supply of river fish. Some of the organisms become available as fish food only after they leave the bottom to become part of the drift. Fishman (1968) found that the energy content of the individuals in the drift was significantly higher than that of those in the benthos. As much as 107 kg/day of microcrustacea and insect larvae were discharged from the Carlyle Reservoir 9 months after first impoundment of the river and used by an increased fish population in the tailwaters and several kilometers downstream (Larimore 1972). Redistribution by drifting invertebrates is particularly important in colonizing woody debris (Nilsen 1968) and areas of a stream that have been denuded of their natural communities through some catastrophe, such as pollution or dredging. Organic drift also served as an index to water quality and provided a greater variety of organisms than could be found in the benthic communities of silt and shifting sand.

During 1982–83, the Illinois Environmental Protection Agency sampled macroinvertebrates at more than 100 sites in the Kaskaskia River basin (Kelly et al. 1989). The organisms collected were used to evaluate water quality. A Modified Macroinvertebrate Biotic Index was calculated based on the relative pollution tolerance of the organisms collected. On an index scale of 0 (intolerant invertebrates found only in clean water) to 11 (tolerant invertebrates occurring even in polluted waters) the index for the basin sites ranged from 4.4 to 8.9, with a mean of 6.0. There were no significant differences among the values calculated for sub-basins of the river. The index indicated degraded waters at six basin sites: four on Richland Creek (Fig.1), downstream from major point sources in the Belleville area, one below Pana's waste treatment plant, and one on a headwater stream with no point source discharges.

Mussels

Forty-two species of mussels have been collected from the Kaskaskia River (Table 4), due largely to the efforts of Baker (1906), Luce (1933), Parmalee and Matteson (1954–56 unpublished records), Brigham (1966–69 unpublished records), and Suloway et al. (1981). The latter paper provides an excellent review of information relative to the mussels of the river, documenting the species collected, their abundance and distribution, a historical comparison of 1954–56 and 1978–79 collections (Table 5), and factors believed responsible for the decline in the river's mussel populations. Documentation for 3 of the 42 species (*Alasmidonta viridis*, *Cumberlandia monodonta*, and *Quadrula fragosa*) is attributed to collections of the Illinois Natural History Survey and other museums (Page et al. 1992).

Baker (1906) collected 25 species, of which 3 (*Elliptio crassidens*, *Ellipsaria lineolata*, and *Leptodea leptodon*) have not been collected since 1906 (Table 4). Luce (1933) added six species (*Plethobasus cyphyus*, *Pleurobema coccineum*, *Alasmidonta marginata*, *Lasmigona costata*, *Lampsilis siliquoidea*, and *Obliquaria reflexa*) to the river's species list. Eight new species (*Fusconaia ebena*,

Table 4. Freshwater mussels (Unionidae) collected from the Kaskaskia River drainage, Illinois. Data are from collections of Illinois Natural History Survey, other museums, and various investigators. Nomenclature follows Turgeon 1988.

Scientific name Common name	Status	Baker 1906	Luce 1933	Parmalee & Matteson[a]	Brigham[b]	Suloway et al. 1981	INHS & other museums
Actinonaias ligamentina Mucket		X	X	X	X	X	X
Alasmidonta marginata Elktoe			X	X	X	X	X
A. viridis Slippershell mussel	SE[c],PX[d]						X
Amblema plicata plicata Threeridge		X	X	X	X	X	X
Anodonta grandis Giant floater		X	X	X	X	X	X
A. imbecillis Paper pondshell				X	X	X	X
A. suborbiculata Flat floater				X			X
Anodontoides ferussacianus Cylindrical papershell				X		X	X
Arcidens confragosus Rock-pocketbook		X	X	X	X	X	X
Cumberlandia monodonta Spectaclecase	SE,FC[e],PX						X
Ellipsaria lineolata Butterfly	SC[f],PX	X					X
Elliptio crassidens Elephant-ear	ST[g],PX	X					X
E. dilatata Spike	SC,PX		X	X	X	X	X
Epioblasma triquetra Snuffbox	SE,PX			X		X	X
Fusconaia ebena Ebonyshell	SC,PX			X			X
F. flava Wabash pigtoe		X	X	X	X	X	X
Lampsilis cardium Plain pocketbook		X	X	X	X	X	X
L. siliquoidea Fatmucket			X	X	X	X	X
L. teres Yellow sandshell		X	X	X	X		X
Lasmigona complanata complanata White heelsplitter		X	X	X	X	X	X
L. costata Fluted-shell	PX		X	X		X	X
Leptodea fragilis Fragile papershell		X	X	X	X	X	X
L. leptodon Scaleshell	SE,FC,PX	X					X
Ligumia recta Black sandshell	PX	X	X			X	X
L. subrostrata Pondmussel				X			X

Table 4. *Continued.*

Scientific name Common name	Status	Baker 1906	Luce 1933	Parmalee & Matteson[a]	Brigham[b]	Suloway et al. 1981	INHS & other museums
Megalonaias nervosa Washboard		X	X	X	X	X	X
Obliquaria reflexa Threehorn wartyback			X	X	X	X	X
Plethobasus cyphyus Sheepnose	ST,PX	X		X		X	X
Pleurobema coccineum[h] Round pigtoe	PX		X	X		X	X
Potamilus alatus Pink heelsplitter		X	X	X	X	X	X
P. ohiensis Pink papershell		X		X	X	X	X
Quadrula fragosa Winged mapleleaf	SE,FE[i],PX						X
Q. metanevra Monkeyface		X			X		X
Q. nodulata Wartyback		X	X	X	X		X
Q. pustulosa pustulosa Pimpleback		X	X	X	X	X	X
Q. quadrula Mapleleaf		X	X	X	X	X	X
Strophitus undulatus Squawfoot		X	X	X	X		X
Toxolasma parvus Lilliput				X			X
Tritogonia verrucosa Pistolgrip		X	X	X	X	X	X
Truncilla donaciformis Fawnsfoot	PX	X		X			X
T. truncata Deertoe		X	X	X		X	X
Uniomerus tetralasmus Pondhorn	ST			X			X

[a] Unpublished records of P. Parmallee and M. Matteson 1954–56.
[b] Unpublished records of W. Brigham 1966–69.
[c] SE = state endangered.
[d] PX = presumed extripated from drainage.
[e] FC = federal candidate.
[f] SC = state candidate.
[g] ST = state threatened.
[h] *Pleurobema cordatum* of early collections.
[i] FE = federal endangered.

Uniomerus tetralasmus, Anodonta imbecillis and *suborbiculata, Anodontoides ferussacianus, Epioblasma triquetra, Toxolasma parvus,* and *Ligumia subrostrata*) were collected by Parmalee and Matteson during the mid-1950's (Suloway et al. 1981).

Fourteen of the 42 species documented from the Kaskaskia River were rare in recent collections and may be extirpated from the river. The Asian clam (*Corbicula fluminea*) was first documented in the lower river in 1979 and is now found throughout the entire river system.

Fifteen of the 39 species collected by previous researchers were not taken by Suloway et al. (1981; Table 4). Their collections showed a 76% reduction in abundance (Table 5), indicating a drastic change in mussel habitats. Reasons cited for the decline were the construction of two flood control reservoirs

(Carlyle Lake and Lake Shelbyville), canalization of the lower 80 km of the river, and construction of a navigation lock and dam just above the river's mouth.

Sedimentation increased not only in the impoundments but also in parts of the river. Fluctuating reservoir water releases caused increased bank erosion and mussel suffocation below the reservoirs. This was confirmed by a 1985 survey of a mussel bed 8 km downstream from Carlyle Lake known to have good diversity. The majority of the heavy-shelled species, such as *Megalonaias nervosa*, had been killed (E. Atwood, Illinois Department of Conservation, Illinois, personal communications).

Barring additional physical modifications of the Kaskaskia River and its tributary streams, the mussel fauna is expected to remain relatively stable. Further reductions in sedimentation and various pollutants may result in the recovery of some species once considered abundant, such as *Actinonaias ligamentina, Amblema plicata, Elliptio dilatata, Fusconaia flava, Lampsilis cardium, Potamilus alatus, Quadrula pustulosa*, and *Strophitus undulatus*. Since impoundment, sizable stocks of *Anodonta grandis, A. suborbiculata, A. imbecillis, Potomilus ohiensis*, and *Quadrula quadrula* have developed in Carlyle Lake. Perhaps the greatest potential danger to the mussels of the Kaskaskia River in the foreseeable future lies with the invasion of the zebra mussel (*Dreissena polymorpha*). The zebra mussel is now abundant above and below the mouth of the Kaskaskia (St. Louis and Cape Girardeau, Missouri) and is expected to invade soon via barges and recreational boats entering the lower reaches of the river.

The harvest of mussels from the Kaskaskia River began around 1900, when the mussel stocks of the Mississippi River were no longer yielding the quantity of shell material needed for the pearl button industry. The U.S. Commissioner of Fisheries Report (1915) stated that in 1913, 83 people using principally hand forks or by wading harvested 1,113 metric tons of mussels and pearls worth $18,045 and $5,925, respectively. In 1922, 60,464 kg of mussel shells, pearls, and slugs were taken; their value was set at $6,600 (Sette 1925). Limited harvest of commercially valuable mussels probably occurred until the pearl button industry collapsed around the mid-1940's. Resumption of harvest on a small scale occurred between 1960 and 1965 to supply shell material for the expanding cultured pearl industry (authors' observations), before the banning of harvest in 1966 from all waters within Illinois except the Illinois River.

Table 5. The number of mussels collected at various stations in the Kaskaskia River in 1954 and 1956 and 1978–79. Nomenclature follows Turgeon 1988 (from Suloway et al. 1981).

Species	1954–56	1978–79
Actinonaias ligamentina	123	2
Alasmidonta marginata	4	2
Amblema plicata	534	242
Anodonta grandis	35	7
A. imbecillis	9	1
Anodontoides ferussacianus	64	0
Arcidens confragosus	13	4
Elliptio dilatata	100	1
Epioblasma triquetra	14	0
Fusconaia flava	424	24
Lampsilis cardium	188	58
L. siliquoidea	86	10
L. teres	67	2
Lasmigona complanata complanata	52	27
L. costata	6	0
Leptodea fragilis	120	52
Megalonaias nervosa	18	7
Obliquaria reflexa	7	2
Plethobasus cyphyus	11	0
Pleurobema coccineum	9	0
Potamilus alatus	59	6
P. ohiensis	30	10
Quadrula metanevra	0	1
Q. nodulata	25	1
Q. pustulosa pustulosa	235	11
Q. quadrula	33	16
Strophitus undulatus	174	6
Toxolasma parvus	6	0
Tritogonia verrucosa	66	6
Truncilla donaciformis	17	0
T. truncata	65	0
Uniomerus tetralasmus	1	0

Fish

Typical of many temperate, warmwater streams found within the upper Mississippi River drainage basin, the Kaskaskia River and its tributary streams support a diverse community of fish, consisting primarily of cyprinids, centrarchids, ictalurids, catostomids, and percids. Much of the knowledge concerning the fish assemblage of the system can be attributed to the efforts of the Illinois Natural History Survey (Forbes and

Richardson 1908; Luce 1933; and Larimore 1970) and the Illinois Department of Conservation (Stinauer 1965; Price 1966, 1967; Fritz 1970; Fritz and Paladino 1972; Bertrand and Atwood 1989). Additional information relative to the basin's fisheries can be found in a number of Illinois Natural History Survey and Illinois Department of Conservation published and unpublished reports.

Smith (1979) documented a total of 199 species of fish (186 native and 13 nonnative) collected from Illinois waters. The number of species collected from the Kaskaskia River and its basin streams includes 110 native and 14 nonnative to the basin (Table 6). Two nonnative species not present at the time of Smith's work are present within the lowermost part of the basin—inland silverside in a perched power lake and bighead carp. Species that move into the lower Kaskaskia from the Mississippi River during high water periods include striped bass, shovelnose sturgeon, bighead carp, and grass carp.

Native species that are rare or extirpated from the basin include alligator gar, largescale stoneroller, gravel chub, western silvery minnow, plains minnow, speckled chub, sturgeon chub, bigeye chub, pallid shiner, bigeye shiner, pugnose minnow, mimic shiner, flathead chub, blue sucker, river redhorse, stonecat, brindled madtom, pumpkinseed, western sand darter, fantail darter, and banded sculpin. Bigeye chub, pallid shiner, and western sand darter are considered state endangered species; bigeye shiner and river redhorse are listed as state threatened species; and the blue sucker is a federal candidate species (Category 2a). Species viewed as either escapees or maintained by various stocking efforts include muskellunge, northern pike, goldfish, grass carp, bighead carp, lake chubsucker, brown bullhead, white catfish, burbot, brook stickleback, inland silverside, spotted bass, and striped bass.

The initial survey of the fishes of the Kaskaskia River conducted by Forbes and Richardson (1908) around the turn of the century included 74 species (Table 6). About 25 years later, Luce (1933) collected 80 species. These counts do not include species that were misidentified but do include two species that have been recently split off from original species and are common enough that they certainly would have been taken by the earlier collectors. Luce noted that "although during certain periods and at certain places, pollution existed to the point of destroying fish or forcing them to abandon affected regions, there has been very little alteration in the kinds present since the surveys of Forbes and associates."

From 1960 to 1970, Larimore and associates worked extensively on the river, conducting a variety of biological investigations (see references listed). During this time, the lower 80 km of the river was canalized for navigation, one flood control reservoir was completed, and another was being constructed. Rotenone, electrofishing, and seining were used to collect 93 species of fish (Table 6). The greatest number of species were taken in the glacial moraine area around Sullivan and Shelbyville (Fig. 1), where 53 species were collected at one station (Larimore 1970). Distinct fish assemblages were recognized in tributaries and associated floodplain pools (Table 7). Because of the great variation in habitats throughout the length of the mainstem, a meaningful community list ranking species by abundance could not be generated for Table 7.

The number of fish collected per hectare in the mainstem varied from 41,990 in the upper reaches to fewer than 3,211 at stations downstream, whereas the total weight varied from 48 to 426 kg/ha (Table 8). These data are for fish actually collected and are not corrected for collecting efficiencies associated with the rotenone. Populations varied from station to station depending on whether the locality sampled was a large deep pool with a few large fish or a shallow pool and riffle containing large numbers of small fish. Some differences in samples from one year to the next at the same station may have been caused by habitat changes during the course of the year or by the exact locality not being sampled. Sampling riffles and other shallow areas gave reliable measures of year class strength that could be expected for most of the river species. Oxbow lakes were found to be important areas for river fish, including the species valued by anglers.

From 1964 to 1972, Illinois Department of Conservation biologists conducted a series of rotenone surveys to determine the composition, abundance, and distribution of fish within the Kaskaskia River basin. These surveys resulted in 66 species being collected. The numerical composition in the upper half of the basin was 7.8% game fish, 10.4% commercial fish, and 81.8% forage fish (Stinauer 1965); composition in the lower half of the basin was 26.0% game fish, 6.8% commercial fish, and 67.2% forage fish (Price 1966).

The weight composition of fish collected in the upper half of the basin was 21.5% game fish, 63.6%

Table 6. Fishes recorded from the Kaskaskia River System. Data from the Illinois Natural History Survey Collections, Illinois Department of Conservation, and miscellaneous records, showing status of species, collection, and period of collecting.

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
Petromyzontidae								
Ichthyomyzon castaneus Chestnut lamprey				X	X		X	
I. unicuspis Silver lamprey			X	X			X	
Polyodontidae								
Polyodon spathula Paddlefish			X			X	X	1
Acipenseridae								
Scaphirhynchus platorynchus Shovelnose sturgeon							X	2
Lepisosteidae								
Lepisosteus oculatus Spotted gar				X			X	
L. osseus Longnose gar		X	X	X	X	X	X	
L. platostomus Shortnose gar			X	X	X	X	X	
L. spatula Alligator gar								3
Amiidae								
Amia calva Bowfin			X	X	X	X	X	
Anguillidae								
Anguilla rostrata American eel			X	X		X	X	
Clupeidae								
Alosa chrysochloris Skipjack herring				X		X	X	
Dorosoma cepedianum Gizzard shad		X	X	X	X	X	X	
D. petenense Threadfin shad	I[b]					X	X	4
Hiodontidae								
Hiodon alosoides Goldeye				X	X	X	X	
H. tergisus Mooneye			X	X		X	X	
Esocidae								
Esox americanus vermiculatus Grass pickerel			X	X	X	X	X	X
E. lucius Northern pike	I					X		5
E. masquinongy Muskellunge	I					X		5
Cyprinidae								
Campostoma anomalum Central stoneroller		X	X	X	X	X	X	

Table 6. *Continued.*

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
C. oligolepis Largescale stoneroller	PX[c]	X					X	6
Carassius auratus Goldfish	I							7
Ctenopharyngodon idella Grass carp	I							8
Cyprinella lutrensis Red shiner		X		X	X	X	X	
C. spiloptera Spotfin shiner		X	X	X		X	X	
C. whipplei Steelcolor shiner		X	X	X		X	X	
Cyprinus carpio Common carp	I	X	X	X	X	X	X	
Erimystax x-punctatus Gravel chub		X						
Hybognathus argyritis Western silvery minnow					X		X	9
H. nuchalis Mississippi silvery minnow		X	X	X			X	
H. placitus Plains minnow							X	9
Hypophthalmichthys nobilis Bighead carp	I							8
Luxilus chrysocephalus Striped shiner		X	X	X	X	X	X	
Lythrurus fumeus Ribbon shiner		X		X		X	X	
L. umbratilis Redfin shiner		X	X	X		X	X	
Macrhybopsis aestivalis Speckled chub			X	X			X	
M. gelida Sturgeon chub	PX		X					
M. storeriana Silver chub		X	X	X	X	X	X	
Nocomis biguttatus Hornyhead chub		X	X	X	X	X	X	
Notemigonus crysoleucas Golden shiner		X	X	X	X	X	X	
Notropis amblops Bigeye chub	SE[d]	X	X		X		X	
N. amnis Pallid shiner	SE	X			X		X	
N. atherinoides Emerald shiner		X	X	X	X	X	X	
N. blennius River shiner			X	X			X	
N. boops Bigeye shiner	ST[e]		X	X			X	

Table 6. *Continued.*

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
N. buccatus Silverjaw minnow		X	X	X	X	X	X	
N. buchanani Ghost shiner			X	X			X	
N. dorsalis Bigmouth shiner				X	X	X	X	
N. shumardi Silverband shiner				X		X	X	
N. stramineus Sand shiner		X	X	X	X	X	X	
N. volucellus Mimic shiner				X			X	9
Opsopoeodus emiliae Pugnose minnow	PX	X	X					6,10
Phenacobius mirabilis Suckermouth minnow		X	X	X	X	X	X	
Phoxinus erythrogaster Southern redbelly dace		X				X	X	
Pimephales notatus Bluntnose minnow		X	X	X	X	X	X	
P. promelas Fathead minnow		X	X	X	X	X	X	
P. vigilax Bullhead minnow		X	X	X	X	X	X	
Platygobio gracilis Flathead chub			X				X	9
Semotilus atromaculatus Creek chub		X	X	X	X	X	X	
Catostomidae								
Carpiodes carpio River carpsucker		X	X	X	X	X	X	
C. cyprinus Quillback		X	X	X	X	X	X	
C. velifer Highfin carpsucker		X	X	X		X	X	
Catostomus commersoni White sucker		X	X	X	X	X	X	
Cycleptus elongatus Blue sucker	FC[f]			X		X	X	
Erimyzon oblongus Creek chubsucker		X	X	X	X	X	X	
E. sucetta Lake chubsucker		X					X	5,6
Hypentelium nigricans Northern hog sucker		X	X	X	X	X	X	
Ictiobus bubalus Smallmouth buffalo			X	X	X	X	X	
I. cyprinellus Bigmouth buffalo			X	X	X	X	X	
I. niger Black buffalo			X	X		X	X	
Minytrema melanops Spotted sucker		X	X	X	X	X	X	

Table 6. *Continued.*

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
Moxostoma carinatum River redhorse	ST	X					X	
M. erythrurum Golden redhorse		X	X	X	X	X	X	
M. macrolepidotum Shorthead redhorse		X	X	X	X	X	X	
Ictaluridae								
Ameiurus catus White catfish	I						X	11
A. melas Black bullhead		X	X	X	X	X	X	
A. natalis Yellow bullhead		X	X	X	X	X	X	
A. nebulosus Brown bullhead		X	X	X			X	6,12
Ictalurus furcatus Blue catfish			X	X		X	X	
I. punctatus Channel catfish		X	X	X	X	X	X	
Noturus exilis Slender madtom			X	X	X	X	X	
N. flavus Stonecat		X		X			X	
N. gyrinus Tadpole madtom		X	X	X	X	X	X	
N. miurus Brindled madtom		X					X	6,13
N. nocturnus Freckled madtom		X	X	X		X	X	
Pylodictis olivaris Flathead catfish		X	X	X	X	X	X	
Apherdoderidae								
Aphredoderus sayanus Pirate perch		X	X	X	X	X	X	
Gadidae								
Lota lota Burbot	I							14
Cyprinodontidae								
Fundulus notatus Blackstripe topminnow		X	X	X	X	X	X	
Poeciliidae								
Gambusia affinis Western mosquito fish			X	X	X	X	X	
Atherinidae								
Labidesthes sicculus Brook silverside		X	X	X	X	X	X	
Menidia beryllina Inland silverside	I							15
Gasterosteidae								
Culaea inconstans Brook sickleback	I						X	7

Table 6. *Continued.*

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
Percichthyidae								
Morone chrysops				X	X	X	X	
White bass								
M. mississippiensis				X		X	X	
Yellow bass								
M. saxatilis	I							8
Striped bass								
Centrarchidae								
Ambloplites rupestris		X	X	X			X	
Rock bass								
Centrarchus macropterus				X	X		X	
Flier								
Lepomis cyanellus		X	X	X	X	X	X	
Green sunfish								
L. gibbosus							X	
Pumpkinseed								
L. gulosus		X	X	X	X	X	X	
Warmouth								
L. humilis		X	X	X	X	X	X	
Orangespotted sunfish								
L. macrochirus		X	X	X	X	X	X	
Bluegill								
L. megalotis		X	X	X	X	X	X	
Longear sunfish								
L. microlophus	I					X	X	8
Redear sunfish								
Micropterus dolomieu		X	X	X	X	X	X	
Smallmouth bass								
M. punctulatus	I			X				12
Spotted bass								
M. salmoides		X	X	X	X	X	X	
Largemouth bass								
Pomoxis annularis		X	X	X	X	X	X	
White crappie								
P. nigromaculatus		X	X	X	X	X	X	
Black crappie								
Percidae								
Ammocrypta clara	SE	X	X	X			X	
Western sand darter								
Etheostoma asprigene		X	X	X	X	X	X	
Mud darter								
E. chlorosomum	X	X	X	X	X	X		
Bluntnose darter								
E. flabellare	PX	X						
Fantail darter								
E. gracile		X	X	X	X	X	X	
Slough darter								
E. nigrum		X	X	X	X	X	X	
Johnny darter								
E. spectabile				X		X	X	
Orangethroat darter								
Percina caprodes		X	X	X	X	X	X	
Logperch								
P. maculata		X	X	X	X	X	X	

Table 6. *Continued.*

Family Species	Status	Forbes and Richardson 1908	Luce 1933	Larimore 1970	Illinois Department of Conservation 1963–72	Illinois Department of Conservation 1982–83	Illinois Natural History Survey	Miscellaneous records[a]
Blackside darter								
P. phoxocephala		X	X	X	X	X	X	
Slenderhead darter								
P. shumardi		X	X	X	X		X	
River darter								
Stizostedion canadense		X		X	X	X	X	
Sauger								
S. vitreum		X		X		X	X	
Walleye								
Sciaenidae								
Aplodinotus grunniens			X	X		X	X	
Freshwater drum								
Cottidae								
Cottus carolinae							X	16
Banded sculpin								

[a] Miscellaneous records:
1 Fishermen reported taking paddlefish in lower river during spring months of 1960's. Following construction of the Carlyle dam, paddlefish have frequently been taken from the tailwater area.
2 Reported to P. Smith (INHS) in 1966 from mouth of river. Probably occurs seasonally in lower river.
3 Luce (1933) and Smith (1979) cited reports of species in lower river.
4 Abundant after 1960 in Baldwin Lake. Probably stocked there.
5 Stocked in Lake Shelbyville or associated pools.
6 Collected by Forbes and Richardson (1908) in upper basin.
7 Probably from purchased bait or released by aquarist.
8 Escaped from stocked lakes or commercial fish farms.
9 Taken in mouth of rivers by D. Garver and J. Newton, IDOC.
10 Reported by IDOC in upper Lake Shelbyville (Wilborn Creek area).
11 Collected by A.W. Fritz (IDOC) in Carlyle Lake. Probably from stocked pond.
12 Single specimen taken by Larimore (1970) from oxbow lake. Probably stocked.
13 Collected by Eastern Illinois University (1971) in tributary in upper basin.
14 Collected near New Athens in 1977 by D. Jones (Peabody Coal Co.) and P. Palidino (IDOC).
15 Stocked in Baldwin Lake, 1975.
16 Collected by M. Braasch (INHS) from tributary in lower basin.

[b] I = invading or introduced.
[c] PX = presumed extripated from drainage. Nomenclature follows Robins 1991.
[d] SE = state endangered.
[e] ST = state threatened.
[f] FC = federal candidate.

commercial fish, and 14.9% forage fish, averaging 79.6 kg/ha. Tributary streams produced an average of 77.2 kg of fish/ha; the river stations produced 416.2 kg/ha. The weight composition of fish collected from the lower half of the basin was 21% game fish, 60% commercial fish, and 19% forage fish, averaging 60.3 kg of fish/ha. Tributary streams yielded 84.8 kg/ha.

Species collected at 50% or more of the stations in the upper half of the basin were green sunfish, white sucker, creek chubsucker, stoneroller, silverjaw minnow, bigmouth shiner, sand shiner, red shiner, redfin shiner, suckermouth minnow, bluntnose minnow, blackstripe topminnow, Johnny darter, blackside darter, yellow bullhead, common carp, bluegill, and longear sunfish. Species collected at 50% or more of the stations sampled in the lower half of the basin were red shiner, green sunfish, bluntnose minnow, fathead minnow, and blackstripe topminnow.

Shoal Creek, the least disturbed of the larger tributary streams in the Kaskaskia River basin, produced 47 species of fish (Price 1967; Fritz 1970a). The importance of tributary streams as

Table 7. The 15 most common fish, ranked in order of decending numerical abundance, taken in floodplain pools and the lower reaches of tributaries of the Kaskaskia River (from Larimore 1970).

Tributaries	Floodplain pools
Red shiner	Gizzard shad
Redfin shiner	Golden shiner
Bluntnose minnow	White crappie
Creek chub	Bigmouth buffalo
Yellow bullhead	Black bullhead
Stoneroller	Carp
Green sunfish	Brook silverside
Johnny darter	Bluegill
Sand shiner	Black crappie
Bigmouth shiner	Blackstripe topminnow
Striped shiner	Largemouth bass
Silverjaw minnow	Fathead minnow
Longear sunfish	Orangespotted sunfish
Hornyhead chub	Mosquitofish
Bluegill	Green sunfish

spawning and nursery areas was clearly evident in Shoal Creek by the number of young-of-the-year fish taken, particularly for bullheads and catfish. The average weight of fish collected per station was 259.1 kg/ha. Silver Creek, a western lower basin tributary produced an average of 281.9 kg of fish/ha (Fritz and Paladino 1972).

As the 1964–72 surveys forewarned of water quality, habitat, and fishery deterioration, Illinois Department of Conservation biologists used rotenone and electrofishing to resurvey the fish community of the Kaskaskia River basin in 1982 and 1983. Eighty-one species of fish were collected (Bertrand and Atwood 1989), 15 more than the number taken by the Illinois Department of Conservation 10 years previously. The difference was attributed more to greater sampling effort (128 stations vs. 77) than to improved stream conditions. There was an increase in the number of stations having game fish, and the weight of game fish taken per station increased from 33.5 to 63.5 kg/ha, possibly because of the influences of the two reservoirs. Green sunfish, yellow bullhead, red shiner, bluegill, blackstripe topminnow, common carp, creek chub, bluntnose minnow, largemouth bass, freshwater drum, and channel catfish were collected at 69 or more of the 128 stations sampled.

The large number of species found in the Kaskaskia River is due to the diversity of riverine habitats, including marsh areas, sand and gravel riffles, deep pools, brushy sloughs, and oxbows. Loss or decrease in these habitats because of drainage and levee projects, channelization, construction of dams and impoundments, pollution, and increased sedimentation has probably been the principal reason for declining abundance or loss of some river species. In marked contrast, those species that thrive in the conditions of reservoirs, especially a number of the catostomids, ictalurids, and centrarchids, have exhibited tremendous increases in their abundance in the river.

At present, the Kaskaskia River fish population seems to be fairly stable. However, the possibility

Table 8. Total numbers and weights (kg) per hectare of all fish collected with rotenone in August 1965 and 1966 at established stations along the Kaskaskia River. The stations are numbered from the headwaters downstream (from Larimore 1970).

Station	1965		1966	
	Numbers	Weights (kg)	Numbers	Weights (kg)
1			6,942.9	157.6
2	6,845.7	26.6	3,966.0	46.4
3	1,437.9	28.3	3,923.9	42.3
4	4,028.7	48.4	3,862.4	49.3
5	1,976.5	32.9	5,019.0	126.6
6	735.3	43.6	5,028.7	71.7
7	1,764.0	19.3	6,824.3[a]	102.0[a]
8	519.2	57.0	2,705.8[b]	63.4[b]
9	744.2	40.3	10,043.2[c]	172.7[c]

[a] Above new Carlyle Lake.
[b] In new Carlyle Lake.
[c] Below new Carlyle Lake.

of installing hydroelectric plants at Lake Shelbyville and Carlyle Lake, continual removal of bottomland timber, more intensive production of row crops, increases in the level of pollutants, and additional physical modifications to the river, its tributary streams, and adjoining lands pose a threat to the fish and other aquatic resources of the river.

Fisheries

Sport Fishing

The first glimpse of sport fishing on the Kaskaskia River was provided by Luce (1933). He noted that fishermen caught smallmouth bass during clear water conditions in the Shelbyville–Sullivan area, largemouth bass and bullheads in the floodplain lakes, and catfish and drum particularly along the lower half of the river. White crappie was probably the most abundant sport species in the river.

The U.S. Fish and Wildlife Service (U.S. Department of Interior 1954) conducted a spot-check survey of the river's sport and commercial fisheries from 1948 to 1951, before construction of Carlyle Lake, and found that the river supported substantial fishing pressure in the Shelbyville–Sullivan area in the upper basin. The principal species caught by sport fishermen were channel catfish, bullhead, common carp, drum, suckers, flathead catfish, smallmouth bass, and buffalofish. In the lower part of the river in the vicinity of Carlyle, the sport catch was common carp, channel catfish, freshwater drum, bullhead, bowfin, gar, and buffalofish, with the first three composing 95% of the catch. Most catfish and bullhead were taken on trotlines. The bottomland lakes were heavily fished by plug and fly fishermen for bass and bluegill. Catch rates for pole and line fishermen ranged from 0.14 to 0.20 fish/h. Values calculated for the annual combined sport and commercial fisheries ranged from $99.82/km in the Carlyle area to $120.28/km in the Shelbyville area. Projections were also made relative to the annual man-days fished (6,027), cost per fishing trip ($22.19), cost per kilogram of fish caught ($1.48), and value of the river's annual sport and commercial fisheries ($42,500).

In the absence of any definitive sport fishing information for the river, the Illinois Department of Conservation initiated a creel census in 1966 in the Carlyle–Keyesport area above the Carlyle dam and the 0.8-km area below the dam as the last segment of the dam was being completed. The purpose was to establish a baseline from which to follow the development of the reservoir and tailwater fisheries. During the 20 April–1 November period, upstream of the dam, the projected boat and bank harvest was 2,112 fish, of which 66.2% were common carp, 16.2% channel catfish, 3.6% largemouth bass, 3.2% each freshwater drum and green sunfish, and 2.5% bullheads (Table 9; Fritz 1967). The catch rate for boat fishermen was 0.48 fish/h and for bank fishermen, 0.98 fish/h. The projected catch for the 0.8-km tailwater area was 20,004 fish, 59.2% being common carp, 9.2% drum, 8.8% crappie, 4.4% bullhead, 3.8% channel catfish, 3.4% green sunfish, 3.3% largemouth bass, and 7.9% composed of 15 other species (Table 10). Boat and bank catch rates were 0.92 and 0.38 fish/h, respectively.

To supplement the anticipated reproduction of largemouth bass, white crappie, black crappie, and black bullhead in the river and bottomland lakes above the dam, small stockings of adult white bass, channel catfish, and largemouth bass fingerlings were made during the summer, when approximately 1,881 ha were impounded.

The creel census was repeated during 1967 from 13 April to 2 November. Reservoir boat fishermen caught a total of 32,041 fish at a rate of 1.34 fish/h (Fritz 1968). Reservoir bank fishermen took 69,594 fish at a rate of 1.07 fish/h. Composition of the combined catch was 44.7% bullhead, 19.4% carp, 11.5% green sunfish, 6.4% largemouth bass, 5.8% drum, 4.9% bluegill, 2.5% crappie, 2.3% channel catfish, and 2.5% composed of 14 other species.

The projected data for the tailwater area indicated that boat and bank fishermen caught a total of 63,225 fish for a combined catch rate of 0.65 fish/h. Composition of the catch was 31.6% common carp, 13.9% drum, 11.2% largemouth bass, 9.9% crappie, 8.0% bullhead, 7.9% green sunfish, 6.8% bluegill, 4.7% channel catfish, and 5.7% composed of 18 other species including eel, paddlefish, bowfin, gar, sauger, and walleye.

The Carlyle Lake and tailwater creel census was continued in 1968, 1969, and 1971 (Tables 9 and 10), to follow changes in the reservoir and tailwater fisheries, inasmuch as maintenance of full pool (9,948 ha) was postponed until 1970 (Fritz 1969, 1970b, 1972).

The bullhead fishery peaked at 44.7% of the 1968 harvest (Table 9) and declined to 4.7% by

1971 (Fritz 1969, 1972). The 1966 and 1967 year classes of white crappie dominated the reservoir harvest by 1969 at 33.8% (Fritz 1970b) and continued to do so until 1971, when they peaked out at 51.6% of the total catch (Fritz 1972). Although 8.5% of the 1968 and 13.6% of the 1971 reservoir harvest were largemouth bass, a good fishery for this species never developed, primarily because of frequent, annual pool level fluctuations during spawning (Fritz 1972). Green sunfish and common carp, which composed 6.5% and 16.7%, respectively, of the 1968 reservoir harvest (Fritz 1969), continued to decline in importance thereafter. Conversely, the harvest of freshwater drum and channel catfish steadily increased during the 1968–71 period to 9.8% and 6.0% of the reservoir catch by 1971.

Results of the 1989 and 1992 Carlyle Lake creel censuses (Table 9) reflect a 25-year-old fishery, 97% of which is composed of four species: white bass, white crappie, channel catfish, and bluegill (Bayley 1992, 1993). Since they were established in 1972, white bass have consistently composed over 50% of the annual reservoir harvest, as indicated in 1989 and 1992. Annually, white crappie and channel catfish each compose about 15–20% of the reservoir catch and bluegill 10–11%.

From 1968 to 1971, Carlyle Lake tailwater boat and bank fishermen harvested fish at a combined rate of 0.58 to 0.83 fish/h (Table 9). In addition to the common carp, which dominated the tailwater angler catch through 1971, other important sport species were crappie, bullhead, bluegill, freshwater drum, green sunfish, and channel catfish. Sharp declines in the harvest of green sunfish, bluegill, bullhead, freshwater drum, and largemouth bass occurred after 1969, whereas the harvest of buffalofish, channel catfish, and yellow bass remained stable or increased slightly (Fritz 1972).

Surveys of tailwater anglers in 1989 and 1992 indicated that white bass, which were established in the lake in 1972, was the dominant species harvested, composing 40.7% and 36.5% of the yearly harvest, respectively (Bayley 1992, 1993). Composing 46–55% of the annual harvest during the same period were common carp, channel catfish, freshwater drum, bluegill, and crappie. As was evident year after year, the species caught and angling success of tailwater anglers was a reflection of fish production in and escapement from the reservoir, especially for species such as white bass, white crappie, bluegill, channel catfish, and freshwater drum.

Because a sizable largemouth bass population never developed at Carlyle Lake during post-impoundment, fingerling bass were stocked in a marsh within the Lake Shelbyville basin in 1969 to provide a source of breeder bass upon impoundment. The following year, adult largemouth bass were stocked in an artificial marsh constructed in the upper part of the lake basin to be used as a rearing pond to annually supplement lake fish stocks (Larimore et al. 1973). The breeder bass and large fingerlings produced in the marsh and rearing pond were released as the lake was impounded in 1971. Bluegill, largemouth bass and smallmouth bass fingerlings, adult white bass, and walleye and northern pike fry were also stocked by the Illinois Department of Conservation in 1971. Except for northern pike, large year-classes of the species stocked were achieved. Large broods of white crappie and black crappie were also produced in 1971 from native stocks present in the river, oxbow lakes, and marshes. Typical of many new impoundments, growth of fish was rapid, and a good sport fishery was established.

In 1972, Lake Shelbyville anglers were surveyed from 1 April to 30 October; 80,521 boat and bank fishermen harvested a total of 252,927 fish for a combined catch rate of 0.68 fish/h (Table 11; Fritz 1973). The fact that 106,299 or 42% of the total catch was largemouth bass pointed out the success of pre-impoundment stockings in the development of a largemouth bass sport fishery. Bluegill, white bass, and black crappie and white crappie combined composed 13.9, 6.9, and 32.4% of the total catch in 1972, respectively. A walleye fishery was developed by 1974 and provided excellent fishing in the tailwater area, the lake, and the Kaskaskia River upstream.

A creel survey was not conducted again until 1976–77 (McNurney 1981). It confirmed that the Lake Shelbyville fishery had not declined as rapidly as the Carlyle Lake fishery (Table 11). White crappie and black crappie composed 62.4% of the 145,439 fish caught during 1 July to 31 October 1976 and 1 May to 31 July 1977. Bluegill, white bass, largemouth bass, and channel catfish composed 6.3, 6.2, 4.3, and 3.1% of the total catch, respectively.

The Lake Shelbyville anglers caught fish at a rate of 0.35 fish/h in 1987 (Bayley 1992). Crappie remained the dominant sport species harvested

Table 9. Carlyle Lake creel censuses, 1966–92. Boat and bank data combined.

Variable	1966	1967	1968	1969	1971	1989	1992
Creel period	20 April– 2 November	13 April– 2 November	1 April– 31 October	1 April– 31 October	1 April– 25 October	15 March– 15 November	15 March– 15 November
Average area (ha)	1,880	4,509	5,814	7,734	9,261	9,947	9,623
Number fishermen	672	19,623	56,945	70,368	82,302	18,287	49,596
Hours fished	2,441	88,780	272,522	371,368	368,738	69,492	303,433
Number fish harvested	2,112	101,635	281,652	344,116	256,959	44,795	117,125
Fish per hour	0.87	1.14	1.12	0.93	0.68	.429	.386
Kilograms fish harvested	797	20,836	93,422	81,088	79,471	11,347	38,543
Kilograms per hour	0.33	0.23	0.34	0.22	0.22	0.16	0.12
Kilograms per hectare	0.42	4.62	16.07	10.48	8.58	1.14	4.00
Hours per fishing trip	3.6	4.5	4.8	5.3	4.5	3.8	4.0
Value of sport fishery[a]	$3,347	$97,723	$283,586	$350,432	$409,864	$365,740	$919,920
Principal species harvested:							
Largemouth bass	76	6,540	24,163	18,573	35,093	249	1,938
Bluegill	31	4,974	28,616	51,825	18,349	4,478	12,675
Green sunfish	68	11,722	18,361	8,310	961	146	0
Crappie	0	2,537	41,175	116,462	132,670	6,342	24,182
Bullheads	52	45,444	104,558	88,224	12,192	83	268
Channel catfish	343	2,284	2,590	3,269	15,387	9,413	17,314
Carp	1,397	19,757	47,145	34,723	12,989	104	272
Drum	68	5,917	11,347	20,338	25,238	167	817
Bowfin	24	1,794	2,330	1,306	1,910	0	0
Yellow bass	0	0	0	159	9,837	21	6
White bass	0	0	0	0	0	23,705	58,871
Sauger/walleye	0	0	0	0	97	11	61
Other species	53	666	1,358	913	1,271	76	721

[a] 1966–71 values based on $4.98 per trip (1965 National Survey of Hunting and Fishing); 1989–92 values based on $20 per trip (National Survey of Fishing, Hunting and Wildlife Associated Recreation—Illinois Report).

Table 10. Carlyle Lake tailwater creel censuses, 1966–92. Boat and bank data combined.

Variable	1966	1967	1968	1969	1971	1989	1992
Creel period	20 April–2 November	13 April–2 November	1 April–31 October	1 April–31 October	1 April–25 October	15 March–15 November	15 March–15 November
Number fishermen	13,285	23,949	65,815	58,164	46,352	26,722	48,541
Hours fished	48,093	96,617	344,574	336,160	189,605	169,940	223,702
Number fish harvested	20,064	63,225	425,461	283,402	109,902	70,695	120,128
Fish per hour	0.42	0.65	0.83	0.83	0.58	.42	.54
Kilograms fish harvested	17,161	25,100	169,239	72,641	54,635	19,257	34,006
Kilograms per hour	0.36	0.26	0.49	0.22	0.29	0.11	0.15
Kilograms per hectare	1,804	2,639	17,788	7,638	5,742	2,024	3,547
Hours per fishing trip	3.6	4.0	5.2	5.8	4.1	3.1	2.9
Value of sport fishery[a]	$66,159	$119,266	$327,779	$289,657	$230,883	$534,440	$970,820
Principal species harvested:							
Bluegill	628	4,315	18,831	33,785	2,186	4,925	8,354
Green sunfish	685	4,993	10,942	7,762	138	58	2,493
Crappie	1,765	6,293	32,977	64,097	11,795	9.167	7,315
Largemouth bass	669	7,060	8,874	5,523	1,188	640	229
Bullheads	778	5,088	26,325	28,552	4,387	764	736
Channel catfish	754	2,993	21,084	10,554	10,971	9,727	12,902
Freshwater drum	1,856	8,795	52,708	51,681	18,068	11,938	10,710
Carp	11,870	19,987	243,783	74,339	52,473	3093	15,621
Buffalofishes	531	472	4,512	1,016	4,848	647	2,186
White bass	0	0	0	0	0	28,774	43,832
Yellow bass	78	625	322	183	1,499	396	47
Sauger/walleye	0	0	63	0	0	49	615
Striped bass hybrids	0	0	0	0	0	478	149
Other species	305	719	4,983	1,352	1,485	39	1,593

[a] 1966–71 values based on $4.98 per trip (1965 National Survey of Hunting and Fishing); 1989–92 values based on $20 per trip (National Survey of Fishing, Hunting and Wildlife Associated Recreation—Illinois Report).

Table 11. Lake Shelbyville creel censuses, 1972–90. Boat and bank data combined.

Variable	1972	1976	1977	1987	1990
Creel period	17 April–31 October	1 July–31 October	1 May–31 July	1 April–29 November	15 March–15 November
Number fishermen	80,521	113,353	202,183	126,855	54,723
Hours fished	350,494	104,727	202,183	376,726	264,481
Number fish harvested	252,927	50,331	95,108	157,975	332,853
Fish per hour	0.68	0.48	0.47	.35	.53
Kilograms fish harvested	69,789	14,559	26,711	40,502	79,843
Kilograms per hour	0.20	0.14	0.13	0.11	0.30
Kilograms per hectare	15.5	3.2	5.9	9.0	17.8
Value of sport fishery[a]	$400,995	$564,498	$1,006,871	$2,537,100	$1,094,460
Principal species harvested:					
Largemouth bass	106,299	3,400	2,835	6,051	1,302
Smallmouth bass	214	0	0	0	0
Sunfishes	35,058	3,640	5,470	13,894	4,554
Crappie	82,005	26,773	63,921	105,614	286,524
Bullheads	5,430	0	0	0	11
Channel catfish	2,849	2,657	1,919	7,880	1,127
White bass	17,360	6,217	2,825	34,168	38,825
Carp	1,233	1,404	480	2,718	84
Drum	862	0	0	0	16
Walleye	754	591	919	2,433	299
Northern pike	52	0	0	0	0
Bowfin	777	0	0	0	0
Other species	34	1,762	3,656	6,448	111

[a] 1972–77 values based on $4.98 per trip (1965 National Survey of Hunting and Fishing); 1987–90 values based on $20 per trip (National Survey of Fishing, Hunting and Wildlife Associated Recreation—Illinois Report).

(105,614 fish) at 58.9% of the total. White bass harvest increased to 19.1%, and bluegill, channel catfish, largemouth bass, and walleye catches remained stable at 7.7, 4.4, 3.4, and 1.4%, respectively. By 1990, 84.4% of the harvest was crappie and 11.7% white bass (Bayley 1993).

The construction of two large reservoirs on the Kaskaskia River and subsequent development of sizable populations of predatory species after impoundment had a decided effect on the river's fish community. Largemouth bass moved upstream from Carlyle Lake in 1967 and 1968 and white bass and largemouth bass from Lake Shelbyville in 1972 and 1974 (up to the small ditches of the headwaters) and produced excellent short-term sport fishing. However, the river populations of cyprinids and other smaller fish were decimated by predation. Predatory species are now an important component of the river's fish community, changing the complex interrelationships between species of river fish. Spawning runs of white bass from Carlyle Lake and Lake Shelbyville, and walleye from the latter, continue to produce fair to excellent spring sport fishing. Largemouth bass are also commonly seen in the river-angler creels, as well as greater numbers of channel catfish and white crappie.

Commercial Fishing

The first known record of harvest (Smith 1898) indicates 68,538 kg of fish valued at $4,714 were caught in 1894. The catch was composed of black bass, buffalofishes, common carp, catfish, crappie, eel, drum, sucker, walleye, rock bass, white bass, and yellow bass. A note in the state [Illinois] Fish Commissioner's Report (1908) placed the value of the 1899 commercial catch at $3,002. A U.S. Commissioner of Fisheries Report (Sette 1925) recorded a 1922 catch of 13,290 kg of common carp, buffalo, catfish, and bullhead valued at $3,720.

Annual commercial catch statistics for the Kaskaskia River (Table 12) are available since 1950, following an agreement between the five upper Mississippi River states to gather catch statistics for each of their respective areas open to commercial fishing. During the 1950–81 period, the annual Kaskaskia River harvest ranged from 41,139 to 30,990 kg, averaging 15,667 kg/year. Following the initiation of a winter trammel net fishing program on the channelized section of the lower 56 km of the river in 1982, the annual harvest from 1982 to 1991 ranged from 41,139 to 134,516 kg, averaging 56,862 kg/year.

Before the impoundment of Carlyle Lake, the principal commercial species taken from the Kaskaskia River in order of abundance were common carp, catfish, buffalofish, carpsucker, and freshwater drum. Within 6 years of impoundment, 50% of the annual river harvest was composed of buffalofish, with the remaining portion of the catch being 25% catfish, 22% common carp, and 3.5% carpsucker, drum, paddlefish, bullhead, gar, bowfin, and grass carp combined.

Seven years following impoundment of Carlyle Lake, populations of common carp, buffalofish, and drum were large enough to support a viable commercial fishery. Amid considerable public opposition, the lake was opened to commercial fishing during January–March 1974, resulting in a harvest of 99,251 kg (Table 13). The following year, when 766,599 kg of fish (primarily bigmouth buffalo) were harvested, public opposition turned to strong public support. From 1974 to 1990, except for 1976 and 1977 when the harvest was stopped because of contaminants, 2,934,270 kg of fish were harvested, with a wholesale value of $1,988,740 and a retail value of $4,574,102. The annual average catch generally ranged from 78 to 85% buffalofish, 12 to 15% carp, and 3 to 5% drum, carpsuckers, gar, and bowfin combined.

A diversity of benefits associated with the commercial fishing program resulted. A valuable, underused food resource was made available to the general public, both locally and regionally. The local business community and commercial fishermen who were permitted retail sales of their catch realized significant economic benefits. Reservoir fishery managers were able to gather biological data on those species that were difficult to collect with standard sampling gear. Breeder-sized catfish were obtained for stocking other waters or for fish swaps with other states. From a fishery management standpoint, perhaps the most beneficial aspect of the program was that it clearly demonstrated an abundant and underused fisheries resource could be harvested with few detrimental effects on the lake's existing sport fish population.

Lake Shelbyville, which differs from Carlyle Lake in that it is deeper (average depth 5.76 m) and clearer, has also developed sizable stocks of buffalofish, carpsucker, and carp. It has not been opened to commercial harvest, however, because of the perceived opposition of sport fishermen and other recreational interests, the fear of killing the

Table 12. Annual Kaskaskia River commercial fish harvest, 1950–91. (Compiled from the Annual Illinois Commercial Fish Harvest Reports, Division of Fisheries, Illinois Department of Conservation.)

Year	Kilograms	Year	Kilograms	Year	Kilograms
1950	12,333.8	1964	19,828.5	1978	13,629.1
1951	10,462.4	1965	11,903.9	1979	17,504.0
1952	8,860.3	1966	10,670.4	1980	23,405.1
1953	27,633.2	1967	11,109.4	1981	29,465.5
1954	3,295.6	1968	14,164.8	1982	41,688.1
1955	10,649.9	1969	31,017.3	1983	134,636.0
1956	4,658.9	1970	15,392.4	1984	93,372.8
1957	14,032.7	1971	22,927.9	1985	46,293.5
1958	14,745.9	1972	12,205.8	1986	55,713.5
1959	15,838.7	1973	21,451.0	1987	52,214.1
1960	23,112.2	1974	13,579.1	1988	50,165.2
1961	24,589.5	1975	13,942.3	1989	52,500.6
1962	17,488.5	1976	5,585.1	1990	41,175.1
1963	22,836.2	1977	6,753.3	1991	42,222.9

highly prized walleye and muskellunge present in the lake, and the existing political climate.

Management Recommendations

1. Develop a consortium of private and public interest groups composed of landowners; natural resource, recreational, and business interests; and local, regional, state, and federal agencies to address existing and future natural resource management issues within the Kaskaskia River basin.
2. Initiate efforts to identify and protect lands, wetlands, and aquatic areas within the basin that are ecologically significant in terms of biological diversity of plant and animal communities, in particular those associated with threatened and endangered species.
3. Strengthen the conservation measures of the Farm Bill. Support the U.S. Soil Conservation Service, soil conservation districts, the Illinois Department of Conservation, and Regional Planning Commission efforts to develop and implement basin soil and water management plans, including such measures as establishing "green belt" corridors, leasing or purchasing riparian easements, developing conservation plans for all agricultural lands, restoring leveed bottomlands, and protecting wetlands, stream banks, and stream flows.

Table 13. Weight (kg) and value (wholesale and retail combined) fishermen received for fish harvested from Carlyle Lake. (Compiled from Annual Reservoir Fishery Reports, Illinois Department of Conservation.)

Year	Weight	Value	Year	Weight	Value
1974	99,250.8	$37,534	1983	200,749.7	$174,135
1975	766,598.5	337,709	1984	59,861.3	54,920
1976			1985	59,722.8	56,538
1977			1986	63,860.5	63,905
1978	268,015.7	181,031	1987	67,492.1	66,929
1979	349,896.0	262,829	1988	44,944.6	40,540
1980	529,482.9	345,942	1989	79,491.3	78,701
1981	291,847.5	242,608	1990	5,128.4	5,303
1982	47,928.3	40,116			

4. Work with the U.S. Army Corps of Engineers to develop reservoir release schedules that maintain optimum downstream flows, have spring and fall pulses to permit movement of fish in the river and onto adjacent floodplains, maximize fish reproduction, and minimize bank erosion in both the river and reservoirs.
5. Identify, with the assistance of the Illinois Environmental Protection Agency and Public Health Service, the sources of pollution within the basin. In cooperation with the Regional Planning Commission and city and county governmental agencies, develop and initiate a plan to reduce or eliminate various types of pollutants.
6. Adjust penalties assessed for violations of natural resource laws, regulations, and policies to be made more commensurate with the degree of degradation or loss of natural resources.

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Case Study of the Pigeon River in the Tennessee River Drainage

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Abstract. The Pigeon River, a headwater tributary to the Tennessee River system, has a length of about 113 km. It is located in the the mountainous region of western North Carolina and eastern Tennessee. The Pigeon River has been significantly degraded since 1908 by industrial discharge from paper mill operations at river kilometer (rkm) 102.1, and further influenced since 1930 by impoundment for hydroelectric power generations at rkm 61.1. The potential for additional adverse effects from other point source discharges and nonpoint source run-off is not well known. Fish samples for the Index of Biotic Integrity (IBI) were collected at four Pigeon River sites and from a single reference site on Little River, Tennessee River drainage. Of a possible 60 IBI index points, three Pigeon River sites consistently rated 38 or fewer points and received an IBI classification no higher than poor. Samples from the only Pigeon River site upstream from industrial discharge and from the Little River reference site rated 48 or higher, with IBI classifications of good or excellent. Management of water resources in the Pigeon River, that is, government permitting and regulation, has allowed industry and hydroelectric generation to dominate use of the river. Most of the Pigeon River does not support recreational uses or biological diversity owing to water pollution and altered stream flow. Recent changes in permitting for the paper mill discharge and relicensing for the hydroelectric plant incorporate more stringent environmental regulations and could do much for restoration of the river's environmental quality.

The Pigeon River in North Carolina and Tennessee has historically suffered environmental degradation from pollution and impoundment. The Tennessee Department of Health and Environment and Tennessee Wildlife Resource Agency, assisted by the Tennessee Valley Authority, initiated biomonitoring on the Tennessee portion of the river in 1988 to assess environmental quality and to document anticipated recovery. This study summarizes historical and recent information, and plans for environmental recovery.

History

Early documentation of the biological effects of pollution in the Pigeon River as a result of industrial waste comes from Hess and Tarzwell (1949), who reported that "desirable food and game fishes have been eliminated from the Pigeon River from Canton to the mouth of the stream," and that the Pigeon River in Tennessee was "definitely obnoxious from the standpoint of taste, color, and odor." As summarized by Bartsch (1959), "color and turbidity greatly influence the optical properties of water and may result in decreased transparency sufficient to deprive aquatic plant life of the solar energy necessary to sustain primary productivity, resulting in damage to aquatic habitat and interference with biotic productivity." Keup and Stewart (1966) reported similar findings and estimated reduction of attached algae as high as 96% downstream from the Champion Paper Company. Destruction of a healthy, diverse algal community extended to the mouth of the Pigeon River and was accompanied by the proliferation of undesirable slime organisms (bacteria and diatoms). Bernhardt et al. (1973) concluded that despite installation of wastewater treatment facilities by Champion in the 1960's, nonregulated pollutants such as color "...are at levels intolerable for life to even approximate existence at prepollution conditions." Wingate and Davies (1980) reported loss of diversity and dominance of pollution-tolerant organisms among the macroinvertebrate community downstream of the Champion discharge. The Tennessee Division of Water Pollution Control (McKinney et al. 1978; Melgaard and McKinney 1980) identified pollution interference with basic food chain functions as a contributing factor in the continuing degradation of the Tennessee portion of the Pigeon River. The algal community in the Tennessee portion of the Pigeon River was seasonally dominated by nuisance blue-green algae (*Oscillatoria* spp. and *Lyngbya* spp.).

Many studies through 1991 (Hess and Tarzwell 1949; Bernhardt et al. 1973; Messer 1973; EA Engineering, Science, and Technology. Inc 1988) document a fish community in the Pigeon River downstream from Canton dominated by pollution-tolerant fish such as gizzard shad (*Dorosoma cepedianum*), common carp (*Cyrinus carpio*), and goldfish (*Carassius auratus*), and an almost complete lack of nongame, riffle-dwelling fish species typical of streams in the region. Adams et al. (1992) described abnormalities in fish health and population dynamics of redbreast sunfish, as well as problems in the fish community of the Pigeon River.

An important linkage exists between the aesthetic quality of a stream and its ability to support a desirable aquatic life and recreation. For example, surveys of fishermen preference (Bartsch 1959) demonstrate that the average fishermen fishes for the whole recreational experience and not merely for food. In a 1985 angler opinion survey conducted by the North Carolina Wildlife Resources Commission, 30.9% of the respondents identified pollution as the primary factor negating a positive fishing experience. In a similar survey, Tennessee Wildlife Resources Agency documented (O'Bara 1986) that quality of physical habitat and good water quality are major factors in the quality of the recreational fishing experience.

Keup and Stewart (1966) recognized that "with clean water, the Pigeon River would have a spectacular sport fishery potential." The Pigeon River in Tennessee could support black bass (*Micropterus salmoides*), sauger (*Stizostedion canadense*), catfish (*Ictalurus punctatus*), and a seasonal trout fishery if pollution were abated. At present, the coffee-colored waters of the Pigeon River are incapable of supporting a balanced fishery and are incompatible with a quality recreational fishing experience. The clean water of tributary streams to the Pigeon River provides dramatic contrast to the heavily colored water from paper mill releases, which furthers the perception of the Pigeon River as polluted, objectionable, and unsuitable for fishing or other recreational experiences.

Study Area Description

Catchment

The Pigeon River originates at the confluence of the East Fork Pigeon and West Fork Pigeon rivers

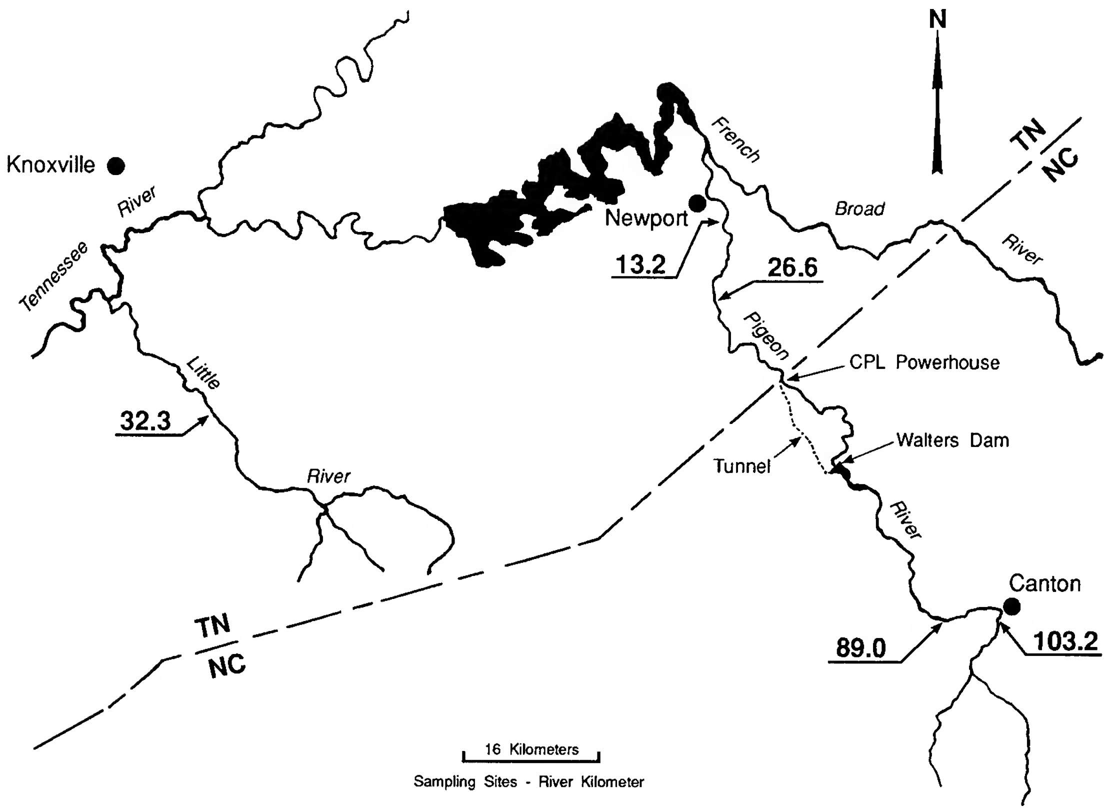

Fig. 1. Study area and IBI sample sites (river kilometer) on the Pigeon and Little rivers.

in Haywood County, North Carolina, and flows 111.8 km northward to the French Broad River in Cocke County, Tennessee (Fig. 1). It has a drainage area of 1,792.4 km^2 (Tennessee Valley Authority 1970). About 85% of the drainage area lies in the Blue Ridge Mountains ecoregion in North Carolina and Tennessee; the remaining area lies in the Central Appalachian Ridges and Valleys ecoregion in Tennessee (Omernik 1987).

From its origin, the Pigeon River drops from an elevation of 803 to 305 m above mean sea level (msl) and joins the French Broad River at river km 119.0. Most of this descent occurs in a 27-km reach between rkm 61 and 34. Here the river passes through a gorge, and gradient averages about 24.1 m/km. Gradient above and below this gorge area averages less than 7.9 m/km. The highest elevation in the drainage (2,018 m) is found on Mt. Guyot.

The geological formation for most of the drainage area is a combination of sedimentary rock underlain by siliceous rock (Hardeman 1966). Minerals in this formation have low solubility. Consequently, the Pigeon River has naturally soft water and low conductivity. Total dissolved solids measure as low as 20 mg/L at sites relatively free of pollution. The Pigeon River is typical of streams in the Tennessee River drainage, and habitat can generally be characterized as riffle, run, or pool. Substrate is predominantly boulder and rubble.

Hydrology

The Pigeon River catchment receives an average annual rainfall of about 128 cm. The estimated average midcatchment inflow is about 805 cubic feet per second (cfs). Maximum midcatchment average inflow is about 1,500 cfs in March, and minimum is 442 cfs in September.

The dominant human-induced hydrologic influences on the Pigeon River include the Champion International, Inc. pulp and paper mill, (rkm 102.3) and Carolina Power and Light's Walters Hydroelectric Project (rkm 61.1). Champion's operation entrains in excess of 166.7 million L/day of Pigeon River water for industrial processing and cooling. During late summer and early fall, flow in the Pigeon River at Canton, North Carolina, may be less than 113.6 million L/day, in which case the entire river is entrained for industrial use. Other features include a low head dam at the mill intake, rkm 63.4, and a small tributary reservoir, Lake

Logan, capable of augmenting flow during critical periods.

About 40 km downstream from Canton, the Pigeon River is impounded by Carolina Power and Light's Walters Hydroelectric Project. The dam is 56.4 m high and 274.3 m wide at the crest, creating Waterville Reservoir, which has a pool 8.4 km long. At maximum pool elevation of 688 m above msl, the surface area is 1.38 km^2. Water is conveyed to the power house through a 9.7-km tunnel cut through the mountains. Use of the tunnel is a daily routine, rarely allowing river flow in a 19.4-km reach of original channel commonly referred to as the by-pass. The by-pass is relatively unaffected by industrial waste unless the dam is overtopped by high water. Local high quality inflow to the by-pass generally exceeds 40 cfs.

The Walters Hydroelectric facility is currently used to produce peak demand electricity and is capable of releasing in excess of 18,000 cfs through three turbine units. During operation of the facility there are frequent occurrences of zero flow in the tailwater and occasional sluicing to expel sediments from the reservoir.

Sources of Carbon, Nutrients, and Contaminants

Historical changes in quantity and quality of carbon and nutrients discharged into the Pigeon River are not well known; however, the river probably has been eutrophic since the paper mill at Canton began operation in 1908. Ownership of the paper mill has changed since the initial operation. The existing National Pollutant Discharge Elimination System permit for Champion International, Inc. lists the following pollutants: TSS, TDS, COD, BOD, pH, odor, colors, tanins, foam, lignins, bacterial, thermal, ammonia, chloroform, sulfides, trichlorophenol, dioxin-furans, and pentachlorophenol. Although the pollutants dioxin and difuran probably have little or no importance as nutrients, they deserve special attention because of their potential toxicity to humans. Dioxin and difuran are by-products of the chlorine bleaching of wood pulp during the paper-making process. Dioxin contamination in fish from the Pigeon River was first documented in 1988 (Schacher 1989). At present, the whole-body dioxin contaminant burden for bottom feeders such as carp ranges from about 15 to 45 parts per trillion (ppt). North Carolina and Tennessee have issued advisories against consumption of fish from the Pigeon River. Action levels for dioxin concentrations in tissue have been set at 5 ppt by Tennessee, 3 ppt by North Carolina, and 25 ppt by the U.S. Food and Drug Administration.

The numbers and types of other point sources discharging to the Pigeon River watershed currently permitted under the National Pollutant Discharge Elimination System include 19 industrial, 1 hydroelectric, 7 municipal, and 42 small domestic sources (U.S. Environmental Protection Agency, unpublished data). Most of these sources discharge downstream of the pulp mill effluent. Industrial and municipal discharges are generally associated with the three largest towns in the catchment: Canton, North Carolina; Waynesville, North Carolina; and Newport, Tennessee. Carbon and nutrients discharged are usually in the form of bacteria and suspended solids (Keup and Stewart 1966; and McKinney et al. 1978).

The amount of pollution coming from nonpoint source run-off is not known. However, increased deforestation of the Pigeon River catchment indicates that nonpoint source run-off and consequential nutrient load have increased. Messer (1973) indicated that 70% of the catchment in North Carolina was forested, and recent estimates (based on Haywood County Soil Conservation Service estimates) show that only 36% is now forested. The catchment in Tennessee is at least 66% forested, based on recent estimates made by the Tennessee Valley Authority. While pollutants originating from nonpoint source run-off may contribute to the detriment of the Pigeon River, there is no evidence that they exceed the effects of Champion's discharge in Canton.

Evaluation of Environmental Quality

Index of Biotic Integrity

A modified version of the IBI (Karr 1981) was used to evaluate environmental quality. The IBI is an assessment of fish community obtained by scoring a fish sample from a given stream site according to 12 metrics (Table 1). These metrics reflect the degree of impairment in species richness and composition (metrics 1-6), trophic structure (metrics 7-9), fish abundance (metric 10), and fish condition (metrics 11-12). Actual values obtained for each metric are scored 1 (severely impaired), 3 (moderately impaired), or 5 (slight or no impairment) against values expected under pristine conditions. The summed scores produce an index that

Table 1. Scoring criteria applied to Index of Biotic Integrity samples from stations on the Pigeon and Little rivers.

Metrics	L. R. km 32.3 scores			P. R. km 13.2 scores			P. R. km 26.5 scores			P. R. km 89.0 scores			P. R. km 103.6 scores		
	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
1.Total number of native fish species	<17	17-33	>33	<17	17-33	>33	<15	15-29	>29	<7	7-13	>13	<7	-13	>13
2.Number of darter species	<4	4-7	>7	<4	4-7	>7	<3	3-5	>5	<2	2-3	>3	<2	2-3	>3
3.Number of sunfish species, less *Micropterus*	<2	2	>2	<2	2	>2	<2	2	>2	0	1	>1	0	1	>1
4.Number of sucker species	<3	3-4	>4	<3	3-5	>5	<3	3-5	>5	<2	2	>2	<2	2	>2
5.Number of intolerant species	<2	2-3	>3	<2	2-3	>3	<2	2	>2	<2	2	>2	<2	2	>2
6.Percentage of fish as tolerant species	>20	20-10	<10	>20	20-10	<10	>20	20-10	<10	>20	20-10	<10	>20	20-10	<10
7.Percentage of fish as omnivores	>30	30-15	<15	>30	30-15	<15	>30	30-15	<15	>30	30-15	<15	>30	30-15	<15
8.Percentage of fish as specialized insectivores	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50	<25	25-50	>50
9.Percentage of fish as piscivores	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
10.Catch rate (average nunber of fish per seine haul or 5-min shocking run)	<8	8-16	>16	<8	8-16	>16	<8	8-16	>16	<7	7-13	>13	<7	7-13	>13
11.Percentage of fish as hybrids	>1	1-Tr*	0	>1	1-Tr*	0	>1	1-Tr*	0	>1	1-Tr*	0	>1	1-Tr*	0
12.Percentage of fish with disease, fin damage, tumors, or other anomalies	>5	5-2	<2	>5	5-2	<2	>5	5-2	<2	>5	5-2	<2	>5	5-2	<2

[a] Values obtained from each sample are scored as follows: 1 = poor, 3 = intermediate, and 5 = the best to be expected. The index of biotic integrity is the sum of the 12 resultant scores.

[b] Tr = value between 0 and 1%.

is then evaluated following Karr et al. (1986; Table 2). The IBI does not necessarily identify the cause of environmental degradation, but reflects the degree of environmental degradation, which often involves toxicity, loss of physical habitat, or eutrophication.

Metric scoring criteria for each sampling site were derived from data and information found in various sources, including Lee et al. (1980), Barr et al. (1986), Karr et al. (1986), Saylor and Ahlstedt (1990), Menhinick (1991), Etnier and Starnes (1992), Saylor (unpublished data), and Tennessee Valley Authority (unpublished data; Table 1). Introduced species, naturally rare species, and young-of-the-year fish are not counted toward metrics 1-5. Catch rate (metric 10) is based on average catch per unit of effort (CPUE), a single seine haul (covering a 4.6- × 6.1-m area) or 5 min of electrofishing (boat or backpack) in combination with a single dip net sample. Scientific and common names of fishes collected during the study follow Robins et al. (1991). Species are presented with designations for tolerant (includes species considered tolerant to various forms of environmental degradation), intolerant (includes species generally considered environmentally sensitive and often absent under adverse enviromental conditions), and trophic guild (Table 3).

Sampling

Fish sampling was done annually during June or July at five sites (Fig. 1). Sampling was done at Pigeon River rkm-13.2 and 26.5 (1988–91), at Pigeon River rkm 89.0 and 103.6 (1990), and at Little River rkm 32.2 (1987-91). Pigeon River rkm 103.6, located in the Blue Ridge Mountains ecoregion, and Little River rkm 32.2, located in the Central Appalachian Ridge and Valley ecoregion, served as reference sites for the two ecoregions involved in the study. Rivers at both reference sites drained mostly national forest or national park lands and were influenced by only limited development in their watersheds. All sample sites included runs, riffles, and pools.

Fishes were sampled using four sampling techniques at each station. In wadable habitats, techniques included backpack electrofishing in combination with a 6.1- × 1.8-m seine, backpack electrofishing in combination with a dip net, and seine hauling. Deeper runs and pools were sampled by electrofishing with a boat-mounted, 230-volt DC generator. To ensure that sampling was qualitatively sufficient, predominant habitats within run, riffle, and pool areas were sampled at each site until no additional species were found in three consecutive units of effort. After each seine haul or shocking run, fish collected were sorted by species, examined for anomalies, counted, and recorded. Most fish were released at the site. Others, retained for closer examination or for voucher specimens, were stored at the Tennessee Valley Authority's Aquatic Biology Laboratory, in Norris, Tennessee.

Results

Findings from the Index of Biotic Integrity clearly showed depressed fish communities at sites down-stream from Canton and relatively healthy fish communities at both reference sites. The condition of fish communities within the Pigeon River is illustrated in Fig. 2. In the following results by site, refer to Table 1 for scoring criteria (expected metric values), Table 2 for classificaitions, and Table 4 for scores and indices.

Pigeon River Kilometer 13.2 (1988–91)

The IBIs at this site ranged from 24 to 38 and can be classified as poor. Most of the 12 metrics received low scores, reflecting severe environmental degradation during all 4 years sampled. Species richness and composition revealed considerable impairment. Numbers of native fish species were low and ranged from 16 to 19 compared with an expected maximum species richness of 51. This loss of diversity involved designated intolerant species as well as numerous species of darters, sunfishes, and suckers. In most samples, there was a high percentage of tolerant fish, mostly gizzard shad.

Trophic structure during 1989 and 1990 indicated excessive nutrient enrichment. During these 2 years, there was an abnormally high percentage of omnivores and a low percentage of piscivores, and to a lesser extent, a low percentage of specialized insectivores.

Problems with fish abundance and fish condition were prevalent. Fish abundance was very low; average catch rate was as low as 5.5 CPUE. A high percentage of fish had anomalies (lesions, fin rot, parasites), which revealed poor environmental conditions for fish health and survival. The occurrence of hybrids (river darter × olive darter) and (sauger × walleye) represented a higher than expected rate of hybridization, considering the small number of fish collected. Hybridization may be

Table 2. Biotic integrity classes used in assessing fish communities along with general descriptions of their attributes (Karr et al. 1986).

Class	Attributes	IBI Range
Excellent	Comparable to the best situations without influence of man; all regionally expected species for the habitat and stream size, including the most intolerant forms, are present with full array of age and sex classes; balanced trophic structure	58–60
Good	Species richness somewhat below expectation, especially due to loss of most intolerant forms; some species with less than optimal abundances or size distribution; trophic structure shows some signs of stress	48–52
Fair	Signs of additional deterioration include fewer intolerant forms, more skewed trophic structure (e.g., increasing frequency of omnivores); older age classes of top predators may be rare	40–44
Poor	Dominated by omnivores, pollution-tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present	28–34
Very poor	Few fish present, mostly introduced or tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular	12–22
No fish	Repetitive sampling fails to turn up any fish	

Table 3. Scientific and common names of fishes collected in this study. Trophic guild, tolerant (Tol), and intolerant (Int) species are indicated.

Scientific name	Common name	Trophic guild	Tolerance
Ichthyomyzon castaneus	Chestnut lamprey	Parasitic	
Lepisosteus oculatus	Spotted gar	Piscivore	
L. osseus	Longnose gar	Piscivore	Tol
Dorosoma cepedianum	Gizzard shad	Omnivore	Tol
Campostoma anomalum	Central stoneroller	Herbivore	
Carassius auratus[a]	Gold fish	Omnivore	Tol
Cyprinella galactura	Whitetail shiner	Insectivore	
C. spiloptera	Spotfin shiner	Insectivore	Tol
Cyprinus carpio[a]	Common carp	Omnivore	Tol
Erimystax insignis[b]	Blotched chub	Omnivore	
Luxilus chrysocephalus[b]	Striped shiner	Omnivore	Tol
L. coccogenis	Warpaint shiner	Specialist	
Lythurus lirus[b]	Mountain shiner	Specialist	
Nocomis micropogon	River chub	Omnivore	
Notropis amblops[b]	Bigeye chub	Specialist	
N. leuciodus	Tennessee shiner	Specialist	
N. photogenis[b]	Silver shiner	Specialist	
N. rubellus	Rosyface shiner	Specialist	

Table 3. *Continued.*

Scientific name	Common name	Trophic guild	Tolerance
N. rubricroceus	Saffron shiner	Specialist	Int[c]
N. spectrunculus	Mirror shiner	Specialist	
N. stramineus[b]	Sand shiner	Specialist	
N. telescopus[b]	Telescope shiner	Specialist	Int
N. volucellus[b]	Mimic shiner	Specialist	
Phenacobius crassilabrum	Fatlips minnow	Specialist	
P.uranops[b]	Stargazing minnow	Specialist	
Pimephales vigilax[b]	Bullhead minnow	Specialist	
Rhinichthys cataractae	Longnose dace	Specialist	
Catostomus commersoni	White sucker	Omnivore	Tol
Carpiodes cyprinus	Quillback	Omnivore	
Hypentelium nigricans	Northern hog sucker	Insectivore	Int
Ictiobus bubalus	Smallmouth buffalo	Omnivore	
I. niger	Black buffalo	Omnivore	
Moxostoma anisurum[b]	Silver redhorse	Insectivore	
M. carinatum	River redhorse	Insectivore	
M. duquesnei	Black redhorse	Insectivore	
M. erythrurum	Golden redhorse	Insectivore	
Ameiurus nebulosa	Brown bullhead	Omnivore	Tol
A. natalis	Yellow bullhead	Omnivore	Tol
Ictalurus punctatus	Channel catfish	Omnivore	
Noturus eleutherus[b]	Mountain madtom	Specialist	Int
Pylodictus olivaris[b]	Flathead catfish	Piscivore	
Fundulus catenatus[b]	Northern studfish	Specialist	
Labidesthes sicculus[b]	Brook silverside	Insectivore	
Cottus bairdi	Mottled sculpin	Insectivore	
C. carolinae	Banded sculpin	Insectivore	
Ambloplites rupestris	Rock bass	Piscivore	
Lepomis auritus[a]	Redbreast sunfish	Insectivore	
L. cyanellus	Green sunfish	Insectivore	Tol
L. gulosus	Warmouth	Piscivore	
L. macrochirus	Bluegill	Insectivore	
L. microlophus[b]	Redear sunfish	Insectivore	
Micropterus dolomieu	Smallmouth bass	Piscivore	
M. punctulatus	Spotted bass	Piscivore	
M. salmoides	Largemouth bass	Piscivore	
Pomoxis annularis	White crappie	Piscivore	
P. nigromaculatus	Black crappie	Piscivore	
Etheostoma blennioides	Greenside darter	Specialist	
E. camurum[b]	Bluebreast darter	Specialist	Int
E. chlorobranchium	Greenfin darter	Specialist	
E. cinereum[b]	Ashy darter	Specialist	
E. jessiae[b]	Blueside darter	Specialist	
E. ruflineatum	Redline darter	Specialist	
E. simoterum	Snubnose darter	Specialist	
E. vulneratum[b]	Wounded darter	Specialist	
E. zonale[b]	Banded darter	Specialist	
Percina aurantiaca	Tangerine darter	Specialist	Int[c]
P. burtoni[b]	Blotchside logperch	Specialist	
P. caprodes	Logperch	Specialist	
P. evides[b]	Gilt darter	Specialist	Int
P. macrocephala[b]	Longhead darter	Specialist	
P. sciera[b]	Dusky darter	Specialist	
P. squamata	Olive darter	Specialist	
Stizostedion canadense	Sauger	Piscivore	
S. vitreum	Walleye	Piscivore	

Table 3. *Continued.*

Scientific name	Common name	Trophic guild	Tolerance
Aplodinotus grunniens	Freshwater drum	Insectivore	

[a] Introduced species.
[b] Species collected from Little River only.
[c] Species used for intolerant only in the upper Pigeon River.

evidence of degraded spawning habitat or reduced availability of spawning partners for species involved.

Pigeon River Kilometer 26.5 (1988–91)

The fish community at this site usually rated lower than at Pigeon River rkm 13.2. Indices ranged from 20 to 32, and classifications ranged from very poor to poor. Species richness and composition were severely impaired. Numbers of native fish species ranged from 12 to 17 compared with an expected maximum species richness of 45. This deficiency involved darter, sunfish, sucker, and designated intolerant species. Species reduction was accompanied by a high percentage of tolerant fish, mostly gizzard shad.

Trophic structure showed more severe and more continuous imbalance than at Pigeon River rkm 13.2. In all 4 years, percentage of omnivores was abnormally high, and percentage of specialized insectivores was low. Percentage of piscivores attained an expected level only in 1991.

Fish abundance and fish condition were also adversely affected. Sampling in 1990 produced the lowest average catch rate (CPUE 3.6) of the entire study. Percentage of diseased (lesions and fin rot), parasitized, or deformed fish in samples was excessive, ranging from 4.8 to 14.8. Hybrid fish, often associated with environmental degradation, were not found.

Pigeon River Kilometer 89.0 (1990)

The resident fish community rated an Index of Biotic Integrity of 22 and a classification of very poor. The severity of impairment was comparable to that found at Pigeon River rkm 16.4. Species richness and composition were depressed. Only 9 of an expected 21 native species were collected. No darter species were found, and numbers of sucker and intolerant species were reduced. Tolerant fish, primarily goldfish, composed 53% of the fish sample, the greatest value obtained for this metric during the study.

Trophic structure at this site exhibited a conspicuous imbalance. Percentage of omnivores was abnormally high, and specialized insectivores and piscivores each constituted less than 1% of the fish collected.

Abnormally low fish abundance and high incidence of anomalous fish reflected extreme environmental degradation. Fish abundance was low (average CPUE 4.8). Forty percent of fish sampled were diseased (primarily lesions), deformed, or parasitized, representing the worst fish condition for the study. No hybrids were collected.

Pigeon River Kilometer 103.6 (1990)

The fish community upstream of the Champion International's discharge had an Index of Biotic Integrity of 58 and a classification of excellent, the highest attained at a sample site during the study. Eleven of the 12 metrics received high scores, reflecting nearly pristine environmental conditions. Species richness and composition showed no impairment. Twenty-one native fish species were collected, including expected numbers of darter, sunfish, sucker, and intolerant species. Tolerant fish were rare and accounted for less than 1% of the sample.

Trophic structure of the fish community was well balanced. Percentages of fish as omnivores (8%), specialized insectivores (52%), and piscivores (14%) were characteristic of a high quality, oligotrophic stream environment.

Fish abundance was considered normal with an average catch rate of 17 CPUE. Percentage of diseased (primarily lesions), deformed, or parasitized fish occurring in the sample (4.8) was considered excessive. Anomalous fish could have moved upstream from Champion's waste discharge, located within 2 km of this site, to influence this finding. No hybrid fish were found.

Little River Kilometer 32.3 (1987–91)

From 1987 through 1991, Index of Biotic Integrity scores for the Little River fish community

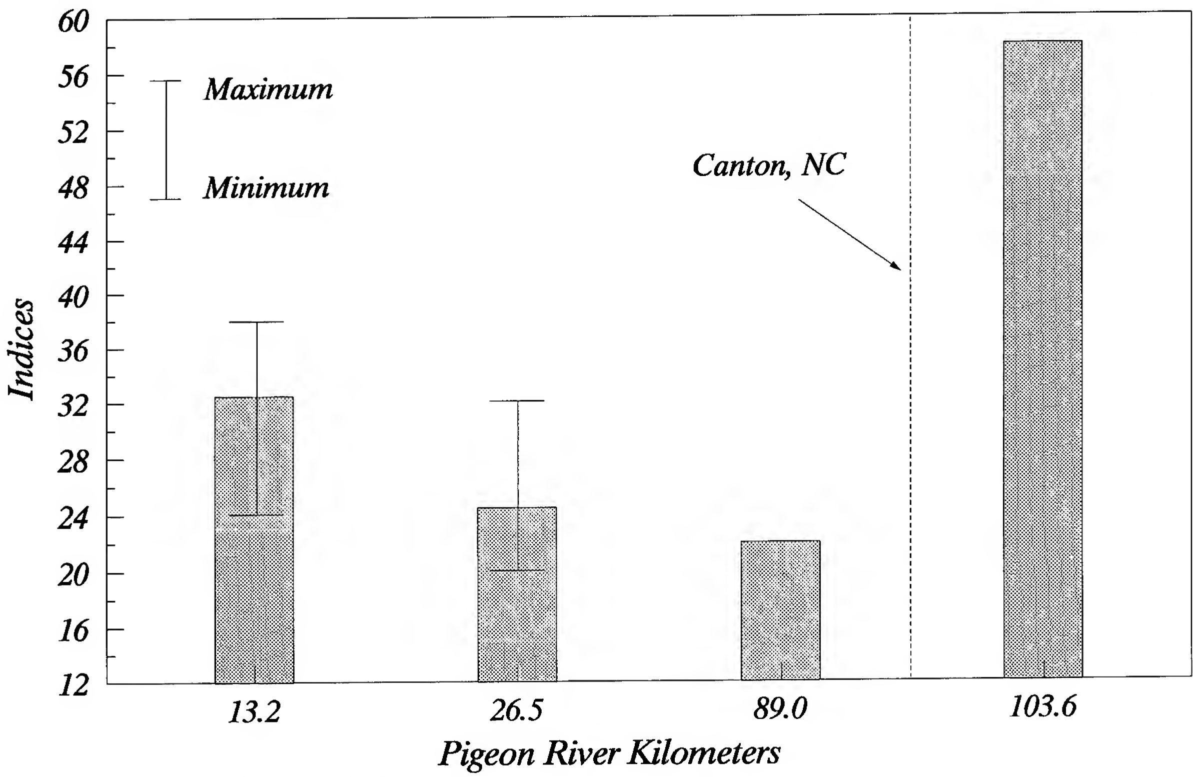

Fig. 2. Range and mean of indices of biotic integrity for samples taken at Pigeon River kilometers 13.2, 26.5, 89.0, and 103.6.

Table 4. Metric scores and indices of biotic integrity for Little River and Pigeon River samples by station and year.

Metrics	Little River km 32.5 Years					Pigeon River km 13.2 Years				Pigeon River km 26.5 Years				km 89.0 Year	km 103.2 Year
	87	88	89	90	91	88	89	90	91	88	89	90	91	90	90
1. Total number of native fish species	5	5	5	5	5	3	3	3	1	3	1	3	3	3	5
2. Number of darter species	5	5	5	5	5	1	1	1	1	1	1	1	1	1	5
3. Number of sunfish species, less *Micropterus*	5	5	3	3	3	1	3	3	3	1	3	3	3	5	5
4. Number of sucker species	3	3	5	5	5	3	3	3	3	3	1	3	1	1	5
5. Number of intolerant species	5	5	5	5	5	1	1	1	1	1	1	1	1	1	5
6. Percentage of fish as tolerant species	5	5	5	5	5	5	1	1	5	1	1	1	3	1	5
7. Percentage of fish as omnivores	5	5	5	5	5	5	3	1	5	1	1	1	3	1	5
8. Percentage of fish as specialized insectivores	3	5	5	5	5	5	5	3	5	1	1	1	3	1	5
9. Percentage of fish as piscivores	5	3	3	3	5	5	3	1	5	1	3	3	5	1	5
10. Catch rate (average no. of fish per seine haul or 5-min shocking run)	3	5	5	5	5	1	1	1	3	1	1	1	1	1	5
11. Percentage of fish as hybrids	3	3	5	5	5	3	5	5	3	5	5	5	5	5	5
12. Percentage of fish with disease, fin damage, tumors, or other anomalies	1	3	3	5	3	5	1	1	3	3	1	1	3	1	3
IBI	48	52	54	56	54	38	30	24	38	22	20	24	32	22	58

ranged from 48 to 56, for a classification of good. Most metrics received high scores in each sample. Species richness and composition showed slight impairment. Number of native fish species varied from 39 to 50 and was comparable to the expected maximum species richness of 51. Samples always included large numbers of darter and intolerant species and a low percentage of tolerant fish. The absence of some sunfish or sucker species from samples reflected slight impairment of the fish community.

Trophic structure showed only slight imbalance. Percentages of omnivores and specialized insectivores usually indicated a high quality stream environment. The percentage of piscivores, however, was often less than expected.

Catch rate was high during most years, averaging 34.9 CPUE in 1988; it was the highest for the study. Some environmental degradation was indicated by poor condition of individual fish. The percentage of hybrids was elevated during 1987 and 1988, and the percentage of anomalous fish (mostly due to parasites, lesions, and fin rot) was at least moderately elevated during most years.

Existing Management of Water Resources

Successful management of water resources integrates and serves the needs of all competitive uses. Seven competitive uses of the Pigeon River are industrial processing-cooling and wastewater discharge, domestic use and wastewater discharge, hydroelectric generation, agriculture (irrigation and livestock), recreational fishing, whitewater rafting-canoeing, and maintenance of aquatic biodiversity. Existing management practices meet the needs of only some of these uses. Current permitting requirements allow river resources to be dominated by industrial use and hydroelectric generation. The Pigeon River downstream of Champion International, Inc. is not processed for domestic use; however, it does receive domestic waste. Agricultural land use has not been inventoried, but Messer (1973) considered croplands and dairy farms an important land use in the river's catchment. Potential effects of agricultural uses on other uses will probably not be known until problems with industrial use and hydroelectric generation are corrected.

Only a small portion of the Pigeon River is managed for recreational fishing. Eleven kilometers of river upstream of Champion International, Inc. effluent and 19.4 km of the partially dewatered by-pass downstream of Walters Dam are managed by North Carolina as coolwater fisheries for smallmouth bass and other sunfish species. The remaining 82.3 km of river support only a depauperate fish population and, because of dioxin contamination, are under state-issued fish consumption advisories. Tributary streams are the main focus of fishery management in the catchment, and most large tributaries support coldwater fisheries based primarily on rainbow trout (*Oncorhynchus mykiss*). Some brown trout (*Salmo trutta*) have been stocked, and isolated populations of brook trout (*Salvelinus fontinalis*) exist in a few higher-elevation streams (J. C. Borawa, North Carolina Wildlife Resource Commission, Asheville, personal communication). Most tributaries are managed as wild trout streams, but some stream reaches are supplemented by stocking in North Carolina and Tennessee.

Opportunities for whitewater rafting and canoeing occur on the Pigeon River downstream from the Carolina Power and Light powerhouse. Water releases from the powerhouse, however, are not scheduled to accommodate this use. Also, poor aesthetics (i.e., water color, foam, odor) detract from such water contact recreation. Restrictions on water contact recreation have not been issued in North Carolina or Tennessee.

Management for biodiversity consists of monitoring for recovery. Much of the biodiversity of the Pigeon River has already been lost, especially in the Tennessee portion of the river, where diversity of aquatic fauna should be greatest. Annual biomonitoring with the Index of Biotic Integrity and benthic macroinvertebrate sampling was initiated by Tennessee in 1988 to obtain baseline data and to document anticipated recovery in the Tennessee portion of the river. Routine biomonitoring of benthic macroinvertebrates by North Carolina's Division of Environmental Management will serve a similar purpose for the North Carolina portion of the river.

Potential Economic Benefits of Pigeon River Restoration

The present polluted condition of the Tennessee segment of the Pigeon River results in very little use for water supply or recreation, but a clean mountain river can have a significant economic effect on a region according to Bach and Barnett (Walter State Community College, Morristown, Tennessee, unpublished report). These authors

evaluated the economic benefits that would be generated by recreational users under the assumptions that the Pigeon River would be suitably cleaned for recreational use, and that the Walters Hydroelectric facility would schedule discharges suitable to favor sport fishing and whitewater floating activities.

Bach and Barnett (unpublished report) also cited the "exceptionally beautiful" aesthetic appeal of the Pigeon River's Tennessee surroundings, including its proximity to the Great Smoky Mountains National Park and the Pisgah National Forest, with an existing national park service campground within 3.2 km of the hydrogenerating facility. Similarily, accessibility by Interstate 40 presents enhanced potential.

In evaluating the recreational floating potential of Tennessee's segment of the Pigeon River, Bach and Barnett (unpublished report) stated that the upper 8.1 km of Whitewater River in Tennessee are rated above two other extremely popular regional whitewater rivers (Nantahala and Hiwassee). Further evaluations of the river's versatility indicate that its downstream segments provide excellent recreational nonwhitewater boating and float-fishing potential.

Sport fishing potential on the Pigeon River was based on creel data for similar regional coolwater and warmwater stream fisheries and for "put, grow, and take" tailwater trout fisheries. The authors also considered hiking, sightseeing, picnicking, camping, and observing floaters.

Following evaluation of these recreational categories, based on 1987 monetary standards (without inflationary factors included), projected direct benefits were derived from recreational use of a clean Pigeon River from 1988 through 1997. For this period, the projected total direct benefits derived from recreational use of a clean Pigeon River averaged $1.83 million/year, with the total economic effect (measuring ripple effects and multiplier effects) averaging $7.33 million/year.

In discussing their analyses, Bach and Barnett (unpublished report) emphasized that these projections are based only on actual user costs, an approach that has been shown to greatly underestimate the benefit of a river. Similarly, their study did not examine the economic effect that a clean Pigeon River would have in attracting new industry, increasing agricultural development, or increasing real-estate values. These categories could outweigh the economic benefits derived from recreational activities.

In North Carolina, plans are being considered to enhance the recreational potential and use of the Waterville Lake area. Following water quality improvements in the Pigeon River, downstream of Canton, North Carolina, Waterville Lake is envisioned as a valuable addition to other recreational opportunities in the area (North Carolina Electric Membership Corporation 1990). Water quality improvement in the lake is anticipated to result in a significant sport fishery. Present estimates are that recreation contributes nearly $54 million to the project area. As many as nine new projects are under discussion, including hiking and horseback trails, campgrounds, boat launches, and parking facilities. Expenditures for these projects are being touted as having significant positive effects on future recreational opportunities and benefits in the area.

Restoration Prospects

Restoration of the Pigeon River for fish and aquatic life and water contact recreation is primarily dependent on abatement of industrial pollution from Champion International, Inc. Champion has initiated a multimillion dollar modernization project intended to meet the more stringent requirements of a 1992 National Pollutant Discharge Elimination System permit. The goals of the project are to reduce water use by 35% to 109.8 MLD, to replace chlorine bleaching with oxygen delignification and replace elemental chlorine with chlorine dioxide (reducing dioxin and difuran), to reduce color loading, to remove soluble odor-inducing gases from the wastewater, and to provide enhanced-process spill control.

The Carolina Power and Light hydrogenerating facility (Pigeon River rkm 41.9) is a second major competitor for use of the Pigeon River. The Walters Hydroelectric Project is currently undergoing relicensing by the Federal Energy Regulatory Commission. Tennessee and North Carolina are formal intervenors in this process, and they anticipate the incorporation of license requirements that include establishing a minimum surface elevation for Waterville Reservoir, to prevent disturbance of dioxin-contaminated sediments, and sustained minimum flow in the Pigeon River bypass. Tennessee is also requesting (1) containment of the contaminated bottom sediments in Waterville Lake, (2) sustained minimum flow releases, (3) prescheduled recreational releases, (4) improved

access, and (5) a thorough characterization of the behavior of dissolved oxygen in the tailwaters.

Two additional regulatory and monitoring functions are necessary to fulfill restoration and maintain environmental quality. The first involves continued establishment and enforcement of effective National Pollutant Discharge Elimination System standards for point source discharges. The second is the development of a nonpoint source pollution abatement strategy for the Pigeon River catchment. This would consist of an assessment of nonpoint source pollution, such as run-off from farms, logging operations, and urban development, followed by implementation of best management practices to improve water quality. A current impediment to this effort in Tennessee and North Carolina is state legislation exempting forestry and agricultural operations from mandatory compliance with the Clean Water Act.

The rate and degree of recovery of biota in the Pigeon River are difficult to predict. The availability of outstanding stream habitat should facilitate recovery once water quality is significantly improved. Numerous, relatively undisturbed tributaries will provide a source of recruitment for most of the biodiversity now missing from the Pigeon River. However, large-river fish and mollusk species, which once occupied the lower reaches of the river, may need to be transplanted from nearby rivers. Abatement of instream color to an acceptable level should allow the return of a balanced algal community.

Restoration of public confidence and use of the Pigeon River may prove more difficult than the technical aspects of pollution abatement and biological recovery. Successful removal of color, foam, and odor, combined with prescheduled recreational releases, will probably attract whitewater enthusiasts to the 8.1-km tailwater reach downstream of the Carolina Power and Light powerhouse and provide the basis for a significant whitewater business.

Achieving full use of the fisheries resource may be a long-term problem. The behavior of dioxin and our ability to alleviate contamination of fish will govern public confidence in the catching and consumption of fish. The stigma of fish contaminated with toxins may be difficult to erase from public memory, even after the contamination has subsided. This process can begin only when North Carolina and Tennessee are able to lift public advisories related to fish consumption.

Conclusion

Findings from Index of Biotic Integrity monitoring of the Pigeon River correspond to findings from earlier biological studies and reveal severe degradation downstream of Champion International, Inc. in Canton, North Carolina. Apparently, pollutants discharged by Champion International, Inc. are the primary cause of degradation. Pollution effects are compounded downstream from the Walters Hydroelectric Project by altered river flows and by sluicing of sediments. For most of the river's length, water pollution and altered flows prohibit full use of river resources, particularly water recreation and biodiversity. To achieve maximum resource use, restoration and maintenance of a healthy river environment is essential. Two important incentives for restoration are projected economic benefits from tourism and public health concerns. Recent steps toward restoration include modernization of the Champion International, Inc. paper mill, a more stringent discharge permit for Champion International, Inc., and proposed improvements in the operation of the Carolina Power and Light hydroelectric plant. Biomonitoring will be continued to assess restoration success.

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Perspectives for Rivers and Their Fishery Resources in the Upper Yazoo River Basin, Mississippi

by

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Abstract. The upper Yazoo River basin is an integrated floodplain river ecosystem located in the Delta region of western Mississippi. The entire system has been modified for flood control purposes, primarily to protect and expand agricultural lands. These flood control measures encompassed upstream headwater impoundments and downstream channelization, including clearing, dredging, and snagging. Flood events, however, still occur, primarily during winter and early spring. In conjunction with soft alluvial soils and mild climate, this flooding encourages natural restoration of stream habitat features affected by the original flood control projects and promotes nutrient exchange dynamics conducive for development and maintenance of exploitable fish stocks. Fish stock assessments were conducted January–August 1990–91 using hoopnets (4.3 m long, seven hoops with 1.07-m diameters, 3.81-cm bar mesh netting) set overnight in the principal tributary streams of the Yazoo River (Coldwater, Little Tallahatchie, Tallahatchie, Yocona, and Yalobusha rivers). Overall mean catch rates were 3.5 ± 0.22 kg/net-night ($N = 1{,}040$ net-nights) for 1990 and 4.2 ± 0.36 kg/net-night ($N = 810$ net-nights) for 1991. Sport and commercially important species accounted for 91.6% of the catch for 1990 and 89.5% for 1991. Catches were dominated by longnose gar *Lepisosteus osseus*, smallmouth buffalo *Ictiobus bubalus*, flathead catfish *Pylodictis olivaris*, common carp *Cyprinus carpio*, and channel catfish *Ictalurus punctatus*. Independent assessments conducted by the U.S. Army Corps of Engineers verify that these resources are similar to stocks supporting excellent riverine fisheries elsewhere in the Mississippi River system. Flood control projects and short interval (about 15 years) maintenance operations for existing projects proposed by special interest groups continue to threaten river fisheries resources throughout the upper Yazoo River basin. These projects, however, are being challenged by natural resources advocates, who contend that reformulation of project designs can address flood control needs while maintaining values associated with the river ecosystems in question.

There is magic in moving water. Swirling currents have captivating powers over persons seeking and sensitive to the rhythms of the earth. We are drawn to rivers not simply for the tangible resources they afford but because they communicate to us the power of eternal forces relentlessly at work. Persons who work and live with rivers eventually transcend the time frame of human experiences and enter into the realm of river time to understand the dynamics of these systems—we must think like a river.

From this perspective, anthropogenic modifications to floodplain rivers are relegated to the realm of minor irritants. These rivers eventually

recover from or adjust to them, albeit some more quickly than others, as erosive forces, climatic influences, geophysical processes, and biological evolution operate. Civilizations pass through a few tumbling generations and then fade away, but the rivers prevail. Therein ultimately dwells hope.

As river resource professionals, we stand firm on the foundation that floodplain rivers and their fisheries are integral, valuable components of our society and that their loss is to the detriment of the quality of life our nation's citizens should enjoy. We therefore find little comfort in geological time, river time, or any other time frame wherein human suffering results from ignorance, greed, neglect, or irresponsible degradation of these lotic ecosystems. Consequently, much of our professional energy is invested in confronting the forces of floodplain river destruction.

Such is certainly the situation with respect to rivers in the upper Yazoo River basin of Mississippi (Fig. 1). The fate of these rivers currently hangs in balance as their resources are assessed

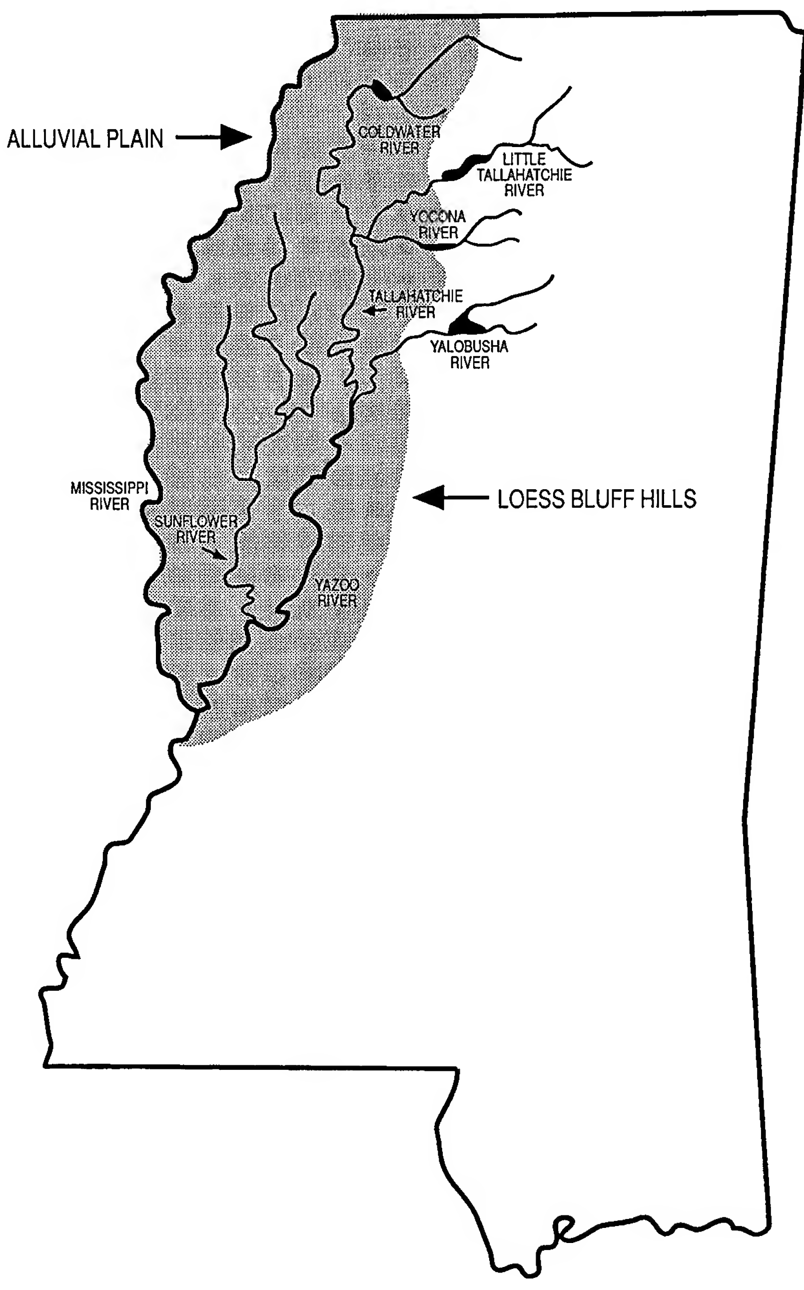

Fig. 1. Principal tributary rivers of the Yazoo River, Mississippi. Impoundments shown are Arkabutla Reservoir (Coldwater River), Sardis Reservoir (Little Tallahatchie River), Enid Reservoir (Yocona River), and Grenada Reservoir (Yalobusha River).

and socio-economic and political priorities are established (see Jackson and Jackson 1989a; Jackson 1991).

Principal Tributary Streams of the Yazoo River

The Yazoo River basin covers about 34,700 km^2 in western and northwestern Mississippi, with about 18,400 km^2 in the Mississippi River alluvial plain (the Delta) and 16,300 km^2 in the loess bluff hill area (U.S. Army Corps of Engineers 1991). There are six principal rivers in the Yazoo River basin that eventually join to form the Yazoo River: the Sunflower River, the Coldwater River, the Tallahatchie River (including the Little Tallahatchie River), the Yocona River, the Yalobusha River, and the Skuna River. In the Delta region these rivers are floodplain river ecosystems; most flooding occurs during winter and spring.

Following the massive and devastating flooding of 1927 in the lower Mississippi River valley, Congress passed a series of Flood Control Acts (1928–65) authorizing flood control projects in the Delta and Yazoo River headwaters. These projects included construction of four flood control reservoirs: Sardis (1937–40, Little Tallahatchie River), Arkabutla (1940–43, Coldwater River), Enid (1947–52, Yocona River), and Grenada (1947–54, Yalobusha and Skuna rivers). No reservoir was constructed on the Sunflower River. The Sunflower River and the downstream reaches of the respective rivers below each reservoir were channelized (including clearing, dredging and snagging), and levees were built. As a result of these activities, the U.S. Fish and Wildlife Service (1979) estimated that more than 80% of the stream reaches of the principal rivers in the Delta were incapable of supporting a fishery of any kind.

The U.S. Army Corps of Engineers has the responsibility of maintaining the flood control projects in the Delta. Before 1973, maintenance of the rivers as flood control channels required only snagging operations and clearing of unsound overhanging trees (U.S. Army Corps of Engineers 1991). Since 1973, however, land clearing and agricultural and residential development, in conjunction with several high-water years, have resulted in sediment deposition in the river channels, restricting flood control operational capabilities of the upstream reservoirs (U.S. Army Corps of Engineers 1991). Within the reservoirs themselves, sediment deposition since their creation has reduced their individual and collective water storage capacities. Floodwaters that the integrated system was originally designed to control now must often be released downstream into river channels less capable of containing these discharges.

According to the U.S. Army Corps of Engineers (1991), the collective design discharge from Sardis, Arkabutla, and Enid reservoirs is 422 m^3/s but this discharge must now be limited to 212 m^3/s during the crop season to prevent flooding of cropland. The maximum discharge below Sardis Reservoir is 180 m^3/s to protect residential property from flooding. The design discharge from Grenada Reservoir is 144 m^3/s, but the discharge usually must be limited to 85 m^3/s to prevent flooding of farmland. Where the principal tributary rivers join above Greenwood, Mississippi, to form the Yazoo River, the design discharge for the system is 566 m^3/s, but this must be reduced during the crop season to 312 m^3/s to prevent flooding of farmland.

The streams have main channels that are generally less than 50 m in width. These widths are considerably less during summer and fall lowflow periods. During bankfull flow regimes, depths ranging to 10 m are common. Deeper holes occur. During lowflow periods, it is often possible to wade across sections of the rivers.

The streams are highly turbid, with Secchi transparencies generally less than 10 cm. Substrates are sand, silt, and clay. Large woody debris is common. This debris can exist as isolated snags or as more complex log jams.

The rivers are not currently used for navigation purposes except by shallow draft commercial and recreational fishing boats. However, gunboat battles were fought on the Yazoo River during the Civil War, and steamboats were common on the river and its main tributaries until the 1920's (Smith 1954). Some steamboats traveled upstream on the Tallahatchie River to locations now inundated by Sardis Reservoir.

The principal land use in the upper Yazoo River basin is for row-crop production, primarily soybeans and cotton. When the main tributary streams of the Yazoo River are at or near bankfull stage as a result of reservoir releases during the growing season, crops can be threatened by flooding from storm runoff. Riparian forest lines most stream reaches throughout the system, but these forests may be narrow corridors that at times are reduced to but a few trees in width. The agricultural practice of clearing to the edge of stream

banks is common throughout the upper Yazoo River basin. Unstable stream banks and substantial land erosion result.

All of the rivers are subject to runoff from agricultural lands. This runoff contains suspended sediments and pesticides. Local residents also use the rivers as their private trash dumps. However, strong currents associated with flood events tend to scour the streams and streambanks, and consequently, the rivers tend to maintain natural aesthetic qualities, as described by Jackson (1991).

To date, recreational and commercial fishing data have not been collected on these rivers beyond the tailwaters of the four major flood control reservoirs. However, passive gear (primarily trotlines and hoop nets) is commonly encountered, as are both commercial fishers and recreational anglers. Fish are routinely collected by the Mississippi Department of Environmental Quality to ensure that no health hazards exist with respect to human consumption. There are no fish health advisories on any of the rivers, and throughout the region there are numerous fish markets that sell fish caught from the principal tributaries of the Yazoo River.

In 1986, the U.S. Army Corps of Engineers announced to the Mississippi Department of Wildlife Conservation (now the Mississippi Department of Wildlife, Fisheries and Parks) the scheduled channel maintenance of the lower 20 km of the Yalobusha River. The maintenance activities would incorporate clearing, dredging, and snagging of this stream reach. Flooding of farmlands would be reduced by a projected 12–15% (U.S. Army Corps of Engineers 1991).

This project subsequently brought public attention to the larger, basinwide Upper Yazoo Headwater Flood Control Project. If completed as originally designed, this project would result in the dredging and snagging of about 420 km of lowland streams and the clearing of about 14,000 ha of the remaining 160,000 ha of bottomland hardwood forests in the Delta (Rude 1988).

In 1989, a federal court order stopped the flood control project pending further information regarding adverse effects on fish and wildlife resources (Jackson and Jackson 1989a). However, information regarding riverine fishery resources of the upper Yazoo River basin was lacking.

Parker and Robinson (1970) provided post-channelization stock assessment data from rotenone samples taken on the Yalobusha River. Several years later, Garavelli (1985) sampled the Yalobusha River with hoop nets and reported that an excellent fishery resource existed. Flathead catfish (*Pylodictis olivaris*) composed 26% of the catch (by weight), and smallmouth buffalo (*Ictiobus bubalus*) and channel catfish (*Ictalurus punctatus*) composed 61.5% of the catch. Jackson and Jackson (1989b, 1989c) concluded that the Yalobusha River contained exploitable stocks of catostomids (primarily buffalofish, *Ictiobus* spp.) and cyprinids (primarily common carp, *Cyprinus carpio*) and an exceptional fishery for flathead catfish.

Fishery resources of the other major tributaries of the Yazoo River were undocumented. The Mississippi Department of Wildlife, Fisheries and Parks, therefore, initiated a comprehensive 5-year riverine fish stock assessment for the upper Yazoo River basin. Systems included in the study were the Coldwater, Little Tallahatchie, Tallahatchie, Yalobusha, and Yocona rivers. The mainstem of the Yazoo was not included because of logistical constraints and because the tributary streams were the systems most threatened by the proposed flood control project. The objective of the study was to determine if fish stocks in these systems were appropriate for exploitation by sport and commercial fisheries. The objective of this report is to describe the results of the first 2 years of that project (1990 and 1991).

Methods

Detailed, independent, and comparative fish stock assessments were conducted for each of the five principal rivers in the upper Yazoo River basin (Jackson and Brown-Peterson 1991; Jackson et al. 1992). However, in Mississippi's bio-political and legal arena, the level of resolution is the entire upper Yazoo River basin. This is a valid scale because the rivers in question are integrated systems with similar instream, riparian, and watershed characteristics, and they are subject to the same prevailing climatic and anthropogenic (primarily agricultural) influences. Therefore, a basinwide level of resolution was used, combining data from all five rivers, to report the results of this investigation.

All sampling for this stock assessment was conducted with unbaited hoopnets (4.3 m long, having seven hoops with 1.07-m diameters and 3.81-cm bar mesh, treated cotton netting). Jackson (1987) conducted gear selectivity studies on the Yalobusha River using electrofishing, gillnets and the hoopnets described above and concluded that the hoopnets set overnight captured more species and,

within species, greater size ranges than were captured with the other techniques. During 1990, total sampling effort was 200 net-nights each in the Little Tallahatchie, Tallahatchie, Yalobusha, and Yocona rivers and 240 net-nights in the Coldwater River. Based on the sample size formula: $n = t^2s^2/d^2$, where n = the number of samples required, t = the tabulated t value for the desired confidence interval and degrees of freedom of the initial sample, s^2 = the sample variance of the original sample, and d = the half-width of the desired confidence interval (Steel and Torrie 1980), applied to 1990 data, total sampling effort during 1991 was adjusted to 200 net-nights each in the Yalobusha and Tallahatchie rivers, 180 net-nights in the Coldwater River, 120 net-nights in the Yocona River, and 110 net-nights in the Little Tallahatchie River. Sampling effort during both years in all rivers was equally distributed between a winter–spring sampling period (January–April) and a summer sampling period (May–August). Sample effort was also evenly distributed among upstream and downstream sections for each river.

Ten hoopnets were set on each sampling date in a randomly chosen 1-km reach. Usually at midday, the nets were placed about 100 m apart with the cod end facing upstream along alternating banks. The nets were checked the following morning. Metal rebar stakes were used to anchor nets in locations where natural instream structure was absent.

Captured fish were identified to species (Robins et al. 1991), measured (total length in millimeters), and weighed (grams), and live fish were marked (fin clip or Floy Anchor Tag, depending on river) and immediately returned to the river. There were few recaptures, but when they occurred catch records were adjusted accordingly to prevent inflation of catch rates and species contributions to catch data. Fish less than or equal to 1,000 g were weighed to the nearest gram. Fish greater than 1,000 g were weighed to the nearest 50 g.

Basinwide stock assessments addressed catch per unit of effort (CPUE; kilograms/net-night), species contribution (percent by weight) to the catch, and mean weights of principal species (species contributing >1% to the total basinwide catch by weight). Comparisons between the 2 years and between the seasonal sampling periods were conducted using analysis of variance (ANOVA) or Student's t-test ($P \leq 0.05$).

Results

For 1990, CPUE for all species collectively was 3.51 ± 0.22 kg/net-night, and for 1991, CPUE was 4.23 ± 0.36 kg/net-night. These catch rates were not significantly different.

Thirty-five species of fish were captured in the rivers of the upper Yazoo River basin in 1990 (Appendix). The suckers (Catostomidae) contributed the greatest number of species (eight), followed by the sunfishes (Centrarchidae, six species), gars (Lepisosteidae, four species), and catfishes (Ictaluridae, four species). Thirty-two species of fish were captured in 1991. As in 1990,

Table 1. Percent catch composition (weight) from principal fishes collected with hoopnets from rivers in the upper Yazoo River basin, Mississippi (1990–91).

Species	Fishery category[a]	Composition (%) 1990	Composition (%) 1991
Longnose gar	Nonclassified[b]	25.06	26.75
Bigmouth buffalo	Commercial	3.82	5.36
Smallmouth buffalo	Commercial	22.91	14.51
Blue sucker	Commercial	3.63	2.50
Common carp	Commercial	8.87	10.02
Blue catfish	Sport/commercial	1.36	3.60
Channel catfish	Sport/commercial	7.05	6.26
Flathead catfish	Sport/commercial	13.28	16.10
Black crappie and white crappie	Sport	1.85	1.21
Freshwater drum	Commercial	3.76	3.21
All other species		8.41	10.48

[a] Categories are according to those recognized by the Mississippi Department of Wildlife, Fisheries and Parks.
[b] Longnose gar are often considered commercial fish and are seasonally in high demand in regional fish markets.

Table 2. Mean weights (grams) and relative standard errors (RSE[a]) of principal fishes caught with hoopnets from rivers in the upper Yazoo River basin, Mississippi (1990–91).

Species	1990 N	1990 Mean weight	1990 RSE	1991 N	1991 Mean weight	1991 RSE
Longnose gar	380	2,382	3.4	383	2,324	3.6
Bigmouth buffalo	79	1,746	4.6	91	1,959	9.1
Smallmouth buffalo[b]	735	1,125	1.8	395	1,222	2.2
Blue sucker	67	1,956	2.5	39	2,129	2.5
Common carp[b]	197	1,626	4.1	153	2,181	3.4
Blue catfish[b]	85	579	13.0	115	1,042	12.9
Channel catfish	258	986	5.7	216	964	4.9
Flathead catfish[b]	214	2,241	8.0	180	2,977	7.9
White crappie[b]	143	442	3.6	111	308	6.5
Freshwater drum[b]	281	484	6.0	133	804	8.8

[a] Relative standard error = standard error/mean expressed as a percentage.
[b] Significant difference in mean weight between years ($P \leq 0.05$).

Catostomidae (seven species), Ictaluridae (six species), Centrarchidae (six species), and Lepisosteidae (four species) contributed the greatest number of species.

The catch composition (percent biomass) was generally consistent during both years and was composed primarily of longnose gar (*lepisosteus osseus*), smallmouth buffalo, flathead catfish, common carp, and channel catfish (Table 1). Sport and commercially important species (including longnose gar) composed more than 91.6% of the catch in 1990 and 89.5% of the catch in 1991. In both years, longnose gar, flathead catfish, smallmouth buffalo, and channel catfish were more prevalent in the summer catch, whereas capture of common carp was highest during the winter–spring sampling period.

Mean weights of all 10 principal species of fish captured from the rivers in the upper Yazoo River basin indicate that all would be attractive for sport or commercial fisheries exploitation, depending on species (Table 2). With the exception of blue catfish, relative standard errors (RSE = standard error/mean) for mean weights of principal species during both years were less than 10%. For blue catfish, RSE was 13.0% in 1990 and 12.9% in 1991. There were, however, significant differences between mean weights of 6 of the 10 principal species between 1990 and 1991. Mean weights of blue catfish, flathead catfish, common carp, freshwater drum (*Aplodinotus grunniens*), and smallmouth buffalo in 1991 were greater than those recorded in 1990. Mean weight of white crappie (*Pomoxis annularis*) decreased between 1990 and 1991. Mean weights of channel catfish, longnose gar, and bigmouth buffalo (*Ictiobus cyprinellus*) were not significantly different between years.

Discussion

Fish stock assessments in the principal tributaries of the Yazoo River documented well-structured and relatively abundant fishery resources (for detailed resolution addressing species and rivers independently see Jackson and Brown-Peterson 1991; Jackson et al. 1992). Independent stock assessments conducted by the U.S. Army Corps of Engineers (1991) confirmed this evaluation. The U.S. Army Corps of Engineers (1991) further stated that the abundance of exploitable fishes collected during its study was similar to the fishery in the lower White River, Arkansas, which is considered to have an excellent commercial fishery (Baker et al. 1989).

These rivers and their associated fishery resources can, within a few decades following channelization, clearing, dredging, and snagging, reestablish themselves as dynamic, temperate, floodplain river systems. In the event that such effects from the proposed flood control programs are again imposed on these rivers, recovery processes will probably be more rapid than before because the upstream flood control reservoirs are filling with silt. As this siltation continues, reservoir capacity to store flood waters will diminish,

and flood events will probably be transferred more quickly downstream.

The strength and duration of flood events will determine the pace of recovery processes in terms of physical instream characteristics of the respective floodplain river ecosystems. This flooding, in conjunction with riparian forest regeneration after clearing (20–25 years in Mississippi), can reestablish the productive dynamics of the systems in terms of exploitable fisheries.

Riparian forests and adjacent overflow areas ultimately determine much of the productive potential for stream fisheries through the introduction of allochthonous organic materials (Vannote et al. 1980; Junk et al. 1989) and snag substrate (Benke et al. 1985). Flooding stimulates detrital processing and primary production within these components of the floodplain river ecosystem (Bayley 1989). This in turn establishes the energetic foundation supporting secondary production and ultimately the fisheries associated with the respective river. Welcomme (1976, 1985, 1986) and Goulding (1980) reported that fish production in floodplain rivers is strongly influenced by the extent and duration of flooding. Flooding stimulates fishery production because fish use the floodplain as a spawning ground, food source, and refuge (Risotto and Turner 1985). In terms of exploitation of fish resources, Holcik and Bastl (1977) found that fish yields from a floodplain river correlated positively with water levels in the river.

Perspectives

The Yazoo River system in the Delta region of western Mississippi has been instrumental not only in establishing the character of the land and its uses but also in formulating a rich cultural heritage. The principal tributary rivers of the Yazoo River were the frontier highways for exploration and commerce that essentially opened the land for settlement. Flooding deposited rich alluvial soils and charged aquifers that are the foundation for the intensive agricultural operations now dominating the landscape. The literature and the arts emanating from the Deep South are replete with images and values associated with turbid, meandering, floodplain rivers (Jackson 1991).

Rather than recognizing the rivers as valuable resources, however, the prevailing position of the economic and political leadership of the region is that the rivers of the upper Yazoo River basin collectively are at best a nuisance and at worst a serious threat to human activities. This leadership continues to advocate out-of-date flood control programs, even though a thorough reformulation process is being conducted for the projects in question. The reformulation process encourages participation, perspective, and expertise from agencies, nonprofit organizations, and citizen's groups with vested interest in the region. Reformulation encourages responsible flood control that operates in concert with the region's river ecosystems, and in so doing promotes values associated with wildlife and fishery resources.

In this last regard, there is increasing awareness that the principal tributary rivers of the Yazoo River system are strongly attractive to recreational anglers and commercial fishers. Given the choice, anglers in Mississippi prefer to fish in streams, and in the Delta, catfishes found in these systems are one of the more sought after groups of fishes (Miranda and Frese 1987, 1989). Commercial fish markets operate in most of the larger towns throughout the Delta, and commercial fisheries operative on rivers in Mississippi are the principal suppliers for these and the regional marketing centers in Memphis, Tennessee (Jackson and Jackson 1989c).

Because of three decades of neglect and lack of channel maintenance, the rivers of the upper Yazoo River basin can no longer be classified as the degraded resources (U.S. Fish and Wildlife Service 1979) they became when originally affected by the flood control projects in the 1940's and 1950's. It seems that most of the recovery in a fishery sense has occurred during the last decade. Additionally, there has been increased public awareness of ecological processes and environmental responsibility and changing regional and national value systems during the past 50 years regarding fish and wildlife resources (when the flood control projects were originally designed). As a result, present-day advocates of the proposed flood control projects—projects that if completed will seriously affect these rivers and their fisheries resources again—are faced with logistical, operational, and political challenges. Their ultimate success in confronting these challenges depends on eroding and, if possible, eliminating current socio-economic and cultural values associated with these rivers. Eroding these values can be facilitated by the U.S. Army Corps of Engineers' (1991) proposed frequency of 15 years between future periodic maintenance activities on the rivers (which flood control advocates prefer to refer to as outlet channels from the up-

stream reservoirs). A 15-year cycle of channel maintenance, which incorporates comprehensive programs of clearing, dredging, and snagging, should be sufficient to curtail recovery of riparian forests (thereby maintaining perpetual energy sinks rather than energy exports to the floodplain river ecosystems); curtail recovery of heterogeneous instream fish habitat (including snag structure, which is a product of mature riparian forests that take 20–25 years to grow); and ultimately, prevent the recovery of associated exploitable fishery resources.

If a critical number of human generations can be forced to live with degraded rivers and degraded fisheries resources, traditions oriented toward interactions with these resources will probably fade (Jackson and Jackson 1989c). However, attempts to take these rivers and their associated fisheries away from society again in Mississippi have been (Jackson and Jackson 1989a) and will be expensive and time-consuming endeavors for river destruction advocates, regardless of whether or not they succeed. During the four decades since the rivers in the upper Yazoo River basin were originally affected by channelization work, these systems have recovered to the point where they are recognized by citizens as valuable natural resources within the public domain. This position has been emphasized by numerous organizations, professional groups, elected officials, and the press, including the Mississippi Wildlife Federation; the Southeastern Section of the Wildlife Society; the Mississippi Chapter of the American Fisheries Society; Mississippi's attorney general (Jackson and Jackson 1989a); Ducks Unlimited (Rude 1988); Jackson, Mississippi's principal daily newspaper, *The Clarion Ledger*, (19 August 1988, 20 August 1988, 17 September 1988, 30 March 1989); and *Mid-South Hunting and Fishing News* (15–28 April 1989). This evolving perspective, however, transcends mere recognition that the river fisheries are recovering. The rivers are in fact being rediscovered as part of a people's identity and, in this sense, are treasures likely to prevail.

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Appendix. Fish species collected with hoopnets from rivers in the Yazoo River Basin, Mississippi (1990–91). Hoopnets were 4.3 m long, with seven hoops having 1.07-m diameters and 3.81 cm bar mesh treated cotton netting. Effort was 1,040 and 810 overnight net sets during 1990 and 1991, respectively.

Family and species	Common name	1990	1991
Polyodontidae			
Polyodon spathula	Paddlefish	x	x
Lepisosteidae			
Lepisosteus oculatus	Spotted gar	x	x
L. osseus	Longnose gar	x	x
L. platostomus	Shortnose gar	x	x
L. spatula	Alligator gar	x	x
Amiidae			
Amia calva	Bowfin	x	x
Anguillidae			
Anguilla rostrata	American eel	x	
Clupeidae			
Alosa chrysochloris	Skipjack herring	x	
Dorosoma cepedianum	Gizzard shad	x	x
Hiodontidae			
Hiodon alosoides	Goldeye	x	x
H. tergisus	Mooneye	x	
Cyprinidae			
Ctenopharyngodon idella	Grass carp	x	
Cyprinus carpio	Common carp	x	x
Catostomidae			
Carpiodes carpio	River carpsucker	x	x
C. velifer	Highfin carpsucker	x	
Cycleptus elongatus	Blue sucker	x	x
Ictiobus bubalus	Smallmouth buffalo	x	x
I. cyprinellus	Bigmouth buffalo	x	x
I. niger	Black buffalo	x	x
Minytrema melanops	Spotted sucker	x	x
Moxostoma poecilurum	Blacktail redhorse	x	x
Ictaluridae			
Ameiurus melas	Black bullhead		x
A. natalis	Yellow bullhead	x	x
A. nebulosus	Brown bullhead		x
Ictalurus furcatus	Blue catfish	x	x
I. punctatus	Channel catfish	x	x
Pylodictis olivaris	Flathead catfish	x	x
Percichthyidae			
Morone chrysops	White bass	x	x
M. saxatilis	Striped bass	x	x
Morone (hybrid)	*Hybrid striped bass*		*x*
Centrarchidae			
Lepomis macrochirus	Bluegill	x	x
L. microlophus	Redear sunfish	x	x
Micropterus punctulatus	Spotted bass	x	x
M. salmoides	Largemouth bass	x	x
Pomoxis annularis	White crappie	x	x
P. nigromaculatus	Black crappie	x	x
Percidae			
Stizostedion canadense	Sauger	x	
Sciaenidae			
Aplodinotus grunniens	Freshwater drum	x	x

The Big Black River, Mississippi: A Case History

by

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Abstract. The Big Black River flows southwesterly 434 km through 11 counties in west-central Mississippi. The 8,770-km^2 drainage area encompasses five physiographic regions. The river joins the Mississippi River 43 km south of Vicksburg, Mississippi. Channel width varies from 27 m at the headwaters to 76 m at its confluence with the Mississippi. Habitat alteration was performed to improve flood control and navigation. Mainstem alterations completed in 1939 included snagging of logjams, cutoff, and bank and channel clearing. Some of the smaller tributaries were altered by 1941, including channel clearing and mouth enlargement. There has been little channel work performed in the last 50 years. Predominant basin land types are forests (57%), cropland (20%), and pastureland (16%). Predominant fish species are the buffalos and catfishes.

With a drainage basin of less than 9,000 km^2, the Big Black River, Mississippi, is a minor tributary of the Mississippi River. Nevertheless, it is important. The Big Black River is the only river in the state's delta region and one of the few in the Mississippi River system that has not been significantly altered. In this paper we review the available literature on the physical aspects of the basin, as well as past and recent data on the biotic community. Given its unique standing, it is unfortunate that this river has not been intensively studied. However, future biotic assessments are planned.

Area description

The Big Black River lies in the Hill Section of central Mississippi (Fig. 1). From its origin in Webster County, the river flows southwesterly for 434 km to its confluence with the Mississippi River, about 43 km downstream from Vicksburg. The drainage basin is about 250 km long and has an average width of 35 km, comprising an area of about 8,770 km^2. Elevations along the river channel range from 15 m National Geodesic Vertical Datum (NGVD) at its confluence to 152 m NGVD at its origin. The slope of the riverbed ranges from 0.47 m/km above Kilmichael to 0.19 m/km below Bovina. The channel is about 27 m wide above Kilmichael and 76 m wide below Bovina.

There are two distinct levels to the floodplain. Directly adjacent to the channel is a narrow, flat, wooded strip that floods two to three times annually. A plateau between the lowland and the hill line floods less frequently and is used for agriculture (Big Black River Basin Coordinating Committee 1968).

Geology

The river basin lies in the south-central portion of the Mississippi Embayment, an extension of the Gulf Coastal Plain. The embayment is underlain by consolidated Paleozoic rock. Clays, silt, sand, and gravel sediments of the Jurassic and Quaternary overlay the bedrock. The topography of the region is characterized by alternating hills and valleys resulting from the differential weathering of outcrop formations. These formations (transecting the basin from northeast to southwest) are grouped into five physiographic regions (Big Black River Basin Coordinating committee 1968; U.S. Department of Agriculture 1968; Hartfield and Rummel 1985):

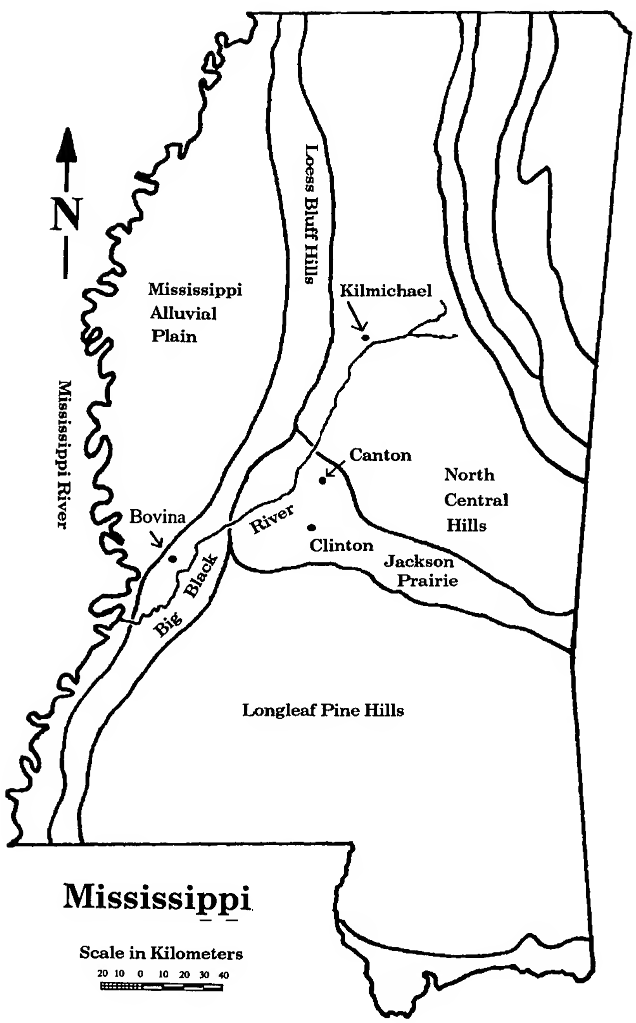

Fig. 1. Geographic location and physiographic regions of the Big Black River in Mississippi.

North Central Hills. This region is composed of irregularly bedded glauconitic or lignitic sands and clays. Outcrop formations are Wilcox and members of the Claiborne Group. The western area is covered by windblown silts. Topographically, the region is a broad upland with many small streams.

Jackson Prairie. Outcrop formations in this area are composed of calcareous clays with some sand and marl. It is principally the Yazoo Clay formation of the Jackson Group. A somewhat thick deposit of silt is found in the western portion. Topographically, it is a rolling area with wide stream bottoms.

Longleaf Pine Hills. Sands, sandstones, clays, marl, and limestone of the Forest Hill and Catahoula formations and Vicksburg group compose the outcrop formations in this region. It is located in the extreme southeast portion of the basin and is a broad, gently sloping to steep upland.

Loess or Bluff Hills. Located in the southwest portion of the basin, this region is thickly covered (up to 15 m) by windblown silts. Underlying formations are the Cockfield, Jackson, Forest Hill, and Catahoula. It is a steep upland with relatively deep gorges.

Mississippi Alluvial Plain. Located in the extreme southwest portion of the basin, this region is composed of Mississippi River alluvia. It is a flat bayou-like region.

Climate

The climate within the basin is strongly influenced by the North American land mass, the basin's latitude, and the Gulf of Mexico. Southerly prevailing winds are the norm during spring and early summer, creating a humid, subtropical environment. Atmospheric changes in summer and early fall result in westerly or northerly winds that bring hotter, drier air. Winters alternate between warm tropical and cold continental air masses.

Temperatures are fairly uniform across regions of the basin; the mean annual temperature is 18° C. Winter and summer temperatures average 10° and 27° C. Annual rainfall averages 1.3 m, and mean monthly rainfall varies from 5 cm in October to 14 cm in March (Big Black River Basin Coordinating Committee 1968; U.S. Department of Agriculture 1968).

Hydrology

As a free-flowing river, prevailing climatic conditions greatly affect flow patterns in the Big Black River. Periods of peak discharge (>200 m^3/s) at the Bovina monitoring station (USGS ID no. 07290000, river km [rkm] 94) occur during February through April. With the onset of the dry period, discharge rates steadily decrease through June, then remain relatively stable from August through October (range, 15–41 m^3/s; Fig. 2). During the dry period, the upper half of the basin provides about two-thirds of the base flow (Big Black River Basin Coordinating Committee 1968). Maximum and minimum flows for the Bovina station are 2,612 m^3/s and 1.5 m^3/s (Mississippi Department of Environmental Quality 1992). Discharge rates at Bovina exceed 2.4 m^3/s 95% of the time (Big Black River Basin Coordinating Committee 1968).

Flood-producing storms can occur in any month but generally are associated with the winter-spring period. The Big Black River Basin Coordinating Committee (1968) briefly described trends in current velocities and periodic overbank flooding following such an event. In the upper reaches of the basin current velocities are relatively swift for a short period. Progressing downstream, velocities decrease, and the period of overbank flooding usually is limited to 2–3 days. In the lower third of the basin, periods of flooding generally are short, given the steep banks and relatively wide channel.

The amount of runoff is a function of soil type, soil moisture, ground cover, rainfall intensity, and season (Big Black River Basin Coordinating Committee 1968). For example, a 2-cm rainfall will result in 0.06 cm of runoff, and a 15-cm rainfall will result in 8.2 cm of runoff from soils of average moisture content. For wet soils, the same amounts of rainfall will produce 0.5 and 11.5 cm of runoff.

Seasonally, about 10% of the average annual runoff of 43 cm/year occurs during late summer through early fall, and 85% occurs during late winter through spring.

Morphology

The river is a fourth-order stream receiving inflow from 134 tributaries ranging from 1 to 24 m in width, with few exceeding 32 km in length. All the main tributaries are perennial, but the smaller streams are either perennial (43%), intermittent (45%), or ephemeral (12%). Their base flows are not large, and the streams on the eastern side of the river have a higher base flow than those on the western side (U.S. Department of Agriculture 1968). The river has a sinuosity value of 1.4, and 21 snags per kilometer were counted (Insaurralde 1992).

In the past some in-stream structure was removed for navigation purposes. From 1884 to 1894 snags were removed from the mainstem, but work ceased pending the removal of several low bridges. In 1894, local residents decided that the bridges were more important than navigation, and snagging for the purpose of navigation never was resumed (U.S. Army Corps of Engineers 1964). Several studies concluded that navigation improvement projects on the river were not feasible (U.S. Army Corps of Engineers 1964). The comprehensive basin study determined that no present or prospective need for navigation existed because historic records did not show considerable commercial navigation on the river (Big Black River Basin Coordinating Committee 1968).

Flooding has long been identified as a basinwide problem, and flood control has been the major rationale for channel modification. In 1939, the U.S. Army Corps of Engineers completed channel improvements consisting of straightening 43 river bends (cutoffs), clearing and snagging, and constructing a 13-km drainage channel in the headwaters (U.S. Army Corps of Engineers 1964). This channel was maintained until 1955; by 1964 it had deteriorated considerably. From 1939 to 1941

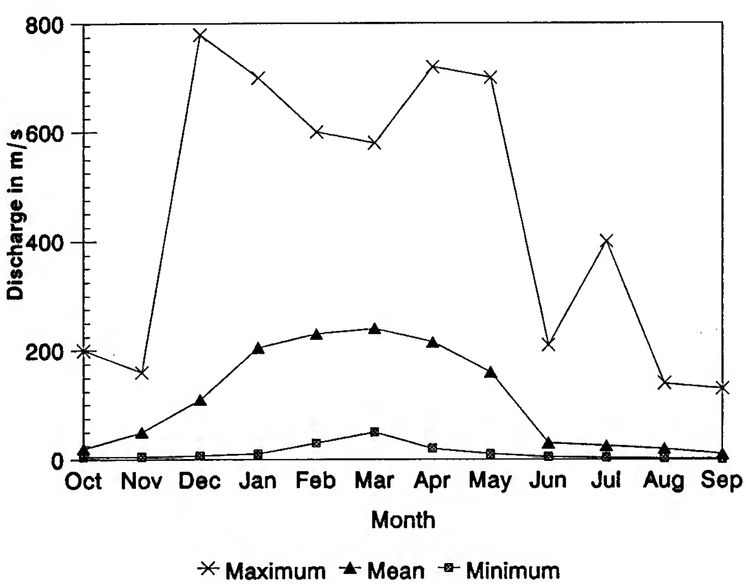

Fig. 2. Mean monthly discharge rates (m^3/s), with historic maximum and minimum discharges, recorded near Bovina, Mississippi (U.S. Geological Survey Station number 07290000), for water years 1939–91. Source: U.S. Geological Survey, Water Resource Data Mississippi, 1939–91.

some tributary mouths were enlarged, and snagging was conducted on 14 streams in the upper basin (U.S. Army Corps of Engineers 1964). Existing drainage basin districts had completed 113 km of channel improvement by 1939, but little work has been performed since then (U.S. Department of Agriculture 1968).

The comprehensive basin study concluded that large-scale flood control projects such as river channel improvements, levees, and reservoirs were not economically feasible (Big Black River Basin Coordinating Committee 1968). Consequently, emphasis was placed on watershed development projects such as floodwater retention structures, land treatment measures (terraces), and the enlargement of tributary channels to alleviate flooding (U.S. Department of Agriculture 1968). Six watershed districts existed in 1968 that had completed 36 floodwater retention structures and 167 km of channel improvements. These retention structures were in the form of small ponds constructed in the headwaters of selected tributaries. The U.S. Department of Agriculture had planned to expand these programs under Public Law 566 by seeking Congressional authorization for 22 watershed plans. The proposed projects included 137 floodwater retention structures, 15 multipurpose reservoirs, and 1,507 km of channel improvements (U.S. Department of Agriculture 1968). None of these watershed plans was implemented because local sponsorship efforts failed.

Watershed Development

At one time, the basin was entirely forested with shortleaf pines and loblolly pines covering the hilltops, while mixed hardwoods were found in the lowlands (Big Black River Basin Coordinating Committee 1968). Increased demand for agricultural lands resulted in the clearing of about 55% of the forest by the late 1940's. However, from the 1940's through the mid-1960's, about 12% of the marginal cropland and pastureland was converted back to timber (U.S. Department of Agriculture 1968). By the end of this period, an estimated 57% of the basin was forested, 23% was used for crops, and 13% was pastureland (the remainder was composed of highways, buildings, etc.).

Insaurralde (1992) used remote sensing techniques to describe current land use patterns and predominant vegetation types within the basin. From National Aircraft Program (NAP) color infrared imagery, the author estimated that 54% of the basin was forested, 11% was pastureland, and cropland accounted for 35% of the remainder. LANDSAT multispectural scanner (MSS) images provided a courser overview of land use than NAP imagery. About 69.9% of the basin was forested, and the remainder was composed of agricultural land based on MSS. As NAP imagery provided the greatest resolution, it would appear the land use in the basin had little changed since the 1960's.

Low-altitude aerial photography was used to estimate the successional stage of vegetation in the riparian zone (Insaurralde 1992). The author described succession as progressing from various species of willows and maples in young forests (10–15 years), to cottonwoods and gum trees (e.g., *Liquidambar styraciflua* and *Nyssa sylvatica*, 40–50 years), climaxing in an oak–hickory forest (≥ 75 years). About 53% of the riparian zone was composed of forested stands with successional stages of greater than 20 years. Only 5.1% of the area lacked vegetation.

A 1981 U.S. Department of Agriculture study classified 69.4% of the basin as an erosion hazard and estimated total annual gross erosion at 7.7 million metric tons/year. Gully formation also was noted; there were about 18,000 active gullies. To reduce agricultural erosion the U.S. Soil Conservation Service instituted two general types of soil management practices. Croplands not directly adjacent to the river or its tributaries were terraced, either in parallel series or following land contours, to maximize the tillable area. Field pipes were used on lands adjacent to the river and tributaries in areas with steep banks to reduce gully formation (D. Vandevere, U.S. Soil Conservation Service, Rankin County, personal communication).

The area is sparsely populated. Insaurralde (1992) reported that the human population density within the basin was 129 inhabitants/km^2. There were 59 population centers classified as not incorporated; seven centers with populations ranging from 250 to 1,000 people; four centers of 1,001 to 5,000 people; and one each with densities of 10,001 to 15,000 and greater than 15,000 people. There were no centers with populations of 5,001 to 10,000 people in the basin.

Surface water withdrawals were limited. In 1968, water diverted for supplemental irrigation was estimated at less than 0.6 million m^3 per year. The Mississippi Department of Environmental Quality has issued five withdrawal permits since 1958; two were for hydrostatic testing by Southern Natural Gas Pipeline, and the other three were for

irrigation. As of 1992, about 0.7 million m^3 per year were used for irrigation (L. Long, Mississippi Department of Environmental Quality, personal communication).

Water Quality

Suspended sediment and chemical concentrations in the Big Black River varied around seasonal periods of low and high flow (Fig. 3). Suspended sediment concentration was lowest during the low-flow period (>50 m^3/s, August through October) and averaged 134.8 mg/L. Mean suspended sediment concentration rapidly increased to 379.9 mg/L during moderate flow rates (50–99 m^3/s), then remained relatively stable up to rates approximating normal high flow (winter/spring, 200–299 m^3/s). With the exception of a peak at the 400–499 m^3/s rate (suspended sediment concentration 931.0 mg/L), suspended sediment concentration was scarcely affected by flood events. Given the soil composition of the basin (predominantly sand and clay), it was likely that only fine particulate matter was incorporated into suspended sediment concentration. While turbid for most of the year, suspended sediment concentration at no time exceeded stressful levels of 20,000 mg/L or lethal levels of 100,000 mg/L, as reported by Winger (1980).

The river discharged soft to occasionally moderately hard water. Total alkalinity averaged 48.4 mg/L and hardness 49.8 mg/L during the low-flow period. Concentrations of titratable bases quickly declined with increasing flow rates, and total alkalinity averaged 19 mg/L when flows were within the 200–299 m^3/s range.

Over the course of the yearly flow cycle, mean nitrate-nitrite concentrations rose from 0.17 mg/L at low flow (>50 m^3/s) to 0.30 mg/L at moderate flow rates (50–99 m^3/s). Levels were somewhat diluted with increasing flows and averaged 0.22 mg/L during the normal high-flow period (200–299 m^3/s). Nitrate-nitrite concentrations peaked at 0.35 mg/L at flows of 400–499 m^3/s, and thereafter declined. These levels did not exceed the 1 mg/L maximum concentration set by the Mississippi Department of Environmental Quality (Mississippi Department of Environmental Quality 1990). Total ammonia and organic nitrogen levels rapidly increased from 0.68 mg/L at low flow to 1.25 mg/L at flows of 50–99 m^3/s. They then remained stable up to flows of less than 200 m^3/s and were diluted with increasing flow rates. There was an increasing trend in total phosphorous levels; mean concentration was 0.18 mg/L during the dry period and 0.31 mg/L during the wet period. Total phosphorous levels were within the acceptable range of 0.15–0.30 mg/L of the state Department of Environmental Quality.

Dissolved oxygen and pH were within the "desirable range for fish production" and Mississippi Department of Environmental Quality standards (>5.0 mg/L and 6.5–9.0, respectively; Winger 1980; Boyd 1990; Mississippi Department of Environmental Quality 1990). Dissolved oxygen rarely dropped below 70% saturation in the mainstem, even during normal low-flow periods. Mean monthly concentrations during late summer and fall ranged from 5.8 to 7.7 mg/L and from 8.9 to 9.3 mg/L during winter and spring. Minimum and maximum pH values ranged from 6.2 to 7.6 with most measurements between 6.8 and 7.2.

In 1992, the Mississippi Department of Environmental Quality reported that the basin was in general compliance with state water quality standards. However, it received an overall "partially supported" fish and wildlife use classification because of unspecified nonpoint source contaminants, elevated fecal coliform concentrations from May through October, and detectable levels of selenium in fish tissue collected at the Bovina station (Mississippi Department of Environmental Quality 1992).

Data concerning sources (but not specific types or concentrations) of pollutants entering the Big Black River and its tributaries were provided by R. Reed, Chief of the Water Quality Monitoring Branch, Mississippi Department of Environmental Quality. In 1992, there were 52 water quality-limited sites and eight effluent-limited sites within the basin. The difference between the two designations was a function of the size of the affected stream. At an effluent-limited site, the base flow was great enough to assimilate the discharged waste products, though the discharge had to meet federal standards (i.e., discharge of raw sewage was not permitted); at a water quality-limited site, the base flow was not sufficient to assimilate discharges, and the permitted facility had to provide treatment exceeding federal standards (R. Reed, personal communication). Eight other sites experienced water quality problems but were not designated water quality-limited or effluent-limited sites.

Progressing from the headwaters to the confluence, 2 of the 52 water quality-limited sites were located in Webster County. While this area fully

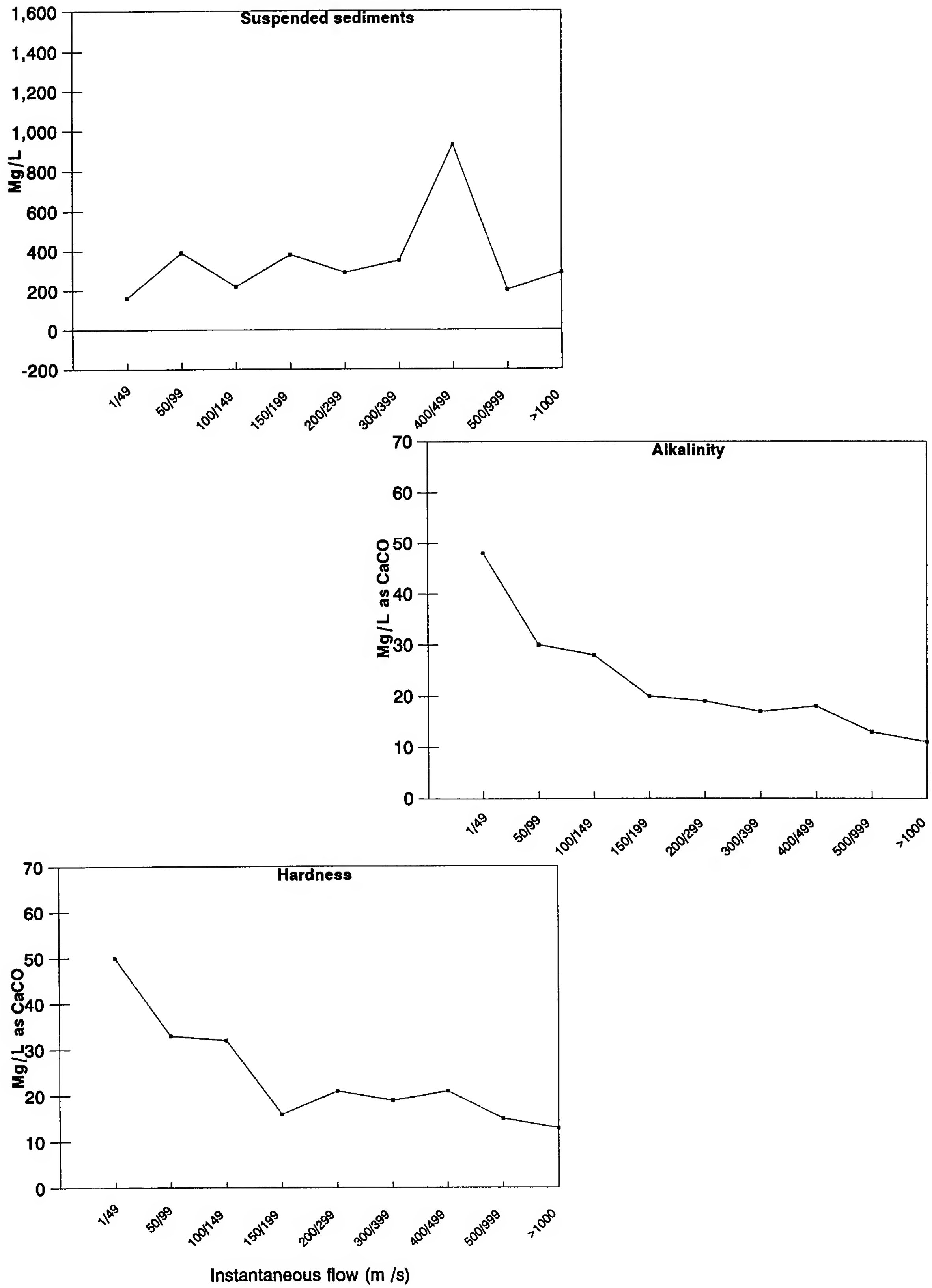

Fig. 3. Means (plus and minus 1 standard deviation) of selected water quality parameters of data collected near Bovina, Mississippi (U.S. Geological Survey Station number 07290000), for water years 1975–91. Source: U.S. Geological Survey, Water Resource Data Mississippi, 1975–91.

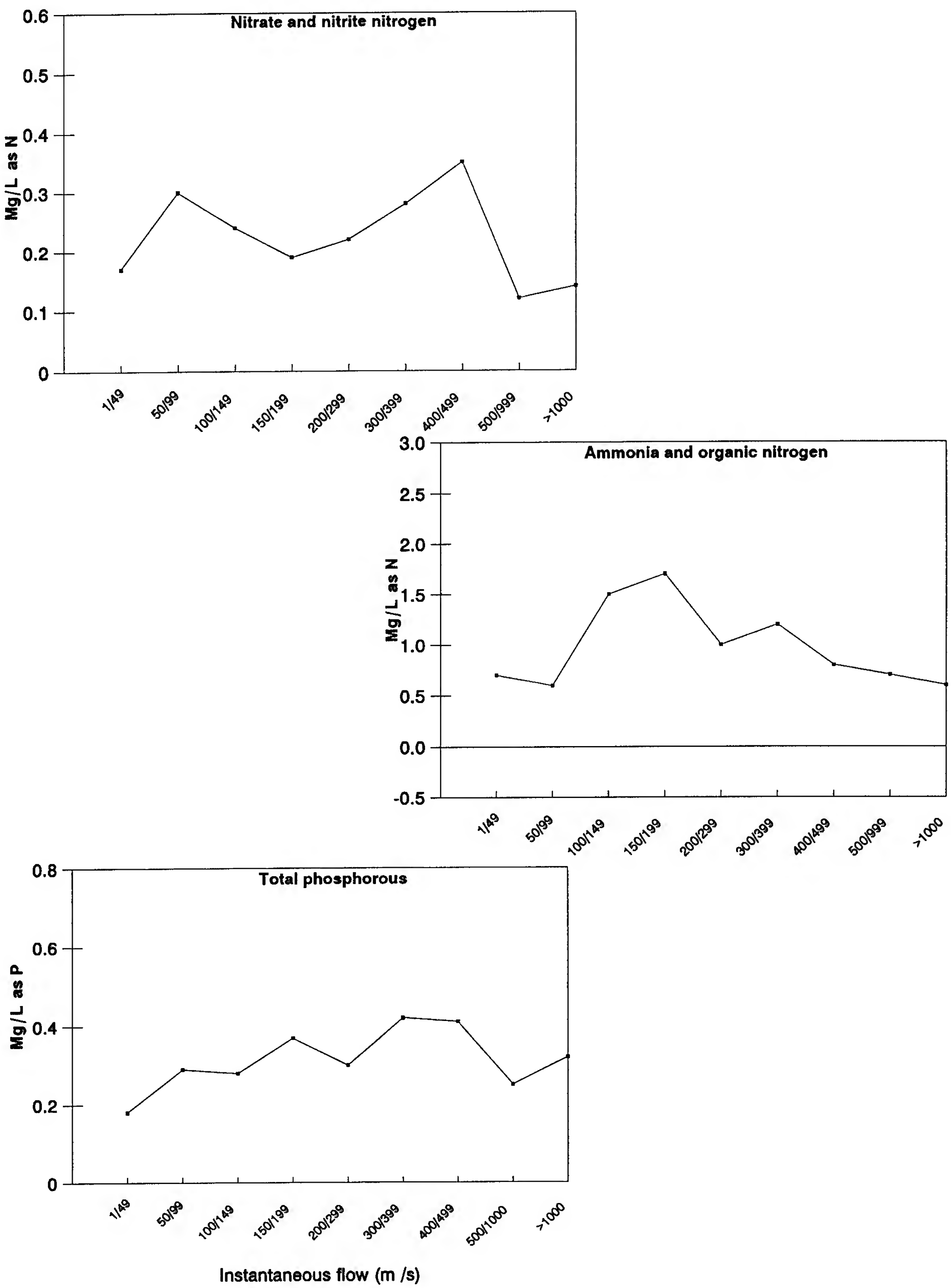

Fig. 3. *Continued.*

supported the fish and wildlife use designation, 22 km of the river were classified as threatened. Unspecified metal contaminants and municipal point-source pollutants from the Eupora area were identified. Madison County accounted for 11 of the water quality-limited sites that were centered around the cities of Canton and Madison. A 12-km section of Bear Creek partially supported its use classification because of elevated levels of nutrients and pathogens. Areas surrounding the population centers of Clinton, Raymond, and Edwards in Hinds County accounted for 22 water quality limited sites. Bakers Creek, located below Clinton, received a threatened classification. Although no water quality limited or effluent limited sites were located in Warren County, 73 km of the river were designated as partially supporting the fish and wildlife use classification because concentrations of nutrients and pathogens, industrial point source and metals, and agricultural nonpoint source contaminants exceeded established limits (Mississippi Department of Environmental Quality 1991).

Aquatic Fauna

One hundred twelve native fish species and two introduced species are known to inhabit the Big Black River (Ross and Brenneman 1991; Table 1). These species represent 47 genera, 18 families, and 12 orders. Species diversity within the river follows the normal pattern of dispersion, with a decrease in the number of species near the headwaters; 79 species have been reported in the upper reaches, 86 in the middle, and 100 in the lower (Ross and Brenneman 1991). The increase in diversity is primarily caused by the increase in cyprinids and catastomids; however, the dominant species remain basically the same throughout the system.

Based on rotenone samples, smallmouth buffalo (37%) was the dominant species throughout the system by weight (Mississippi Department of Wildlife, Fisheries, and Parks, unpublished data; Table 2). Smallmouth buffalo had a mean total length of 378 mm and a mean weight of 1.06 kg. Flathead catfish, with a mean length of 306 mm and mean weight of 0.82 kg, composed 6.6% of rotenone samples. Game fish, including largemouth bass, spotted bass, white crappie, black crappie, and other sunfish totaled 23% of the sample. Paddlefish composed 6% and blue suckers 2.6% of rotenone samples.

Trends in relative abundance and stock structure were observed in some species. Numbers of smallmouth buffalo increased from the headwaters toward the lower reaches, but mean weight remained virtually unchanged. Flathead catfish numbers and weights, on the other hand, were highest in the headwaters and progressively decreased downstream. Blue catfish and largemouth bass numbers were highest in the uppermost reach, but these species were absent in the lowest reach. Channel catfish were most numerous in the middle reaches.

In 1988 electrofishing yielded a total catch per unit of effort (CPUE) of 102.4 fish/h (SE = 13 fish/h) for all species (Table 3; Mississippi Department of Wildlife, Fisheries, and Parks, unpublished data). Smallmouth buffalo exhibited the highest CPUE at 13.1 fish/h (SE = 2.5 fish/h). Gizzard shad (CPUE = 11.78 fish/h) was the next most common species. Species classified as game fish had a combined CPUE value of 20.3 fish/h (SE = 4.1 fish/h); bluegill was the most common (10.5 fish/h).

In a study targeting flathead catfish, Jackson et al. (1990) reported CPUE for flathead catfish in hoopnets to be 0.62 fish/net night and 2.3 kg/net night; several large fish (≥23 kg) were captured. Jackson and Francis (1991) found no change in flathead catfish stock structural indices in the river since 1989. Channel catfish (0.4 fish/net night) and blue suckers (0.2 fish/net night) exhibited the next highest CPUE values in hoopnets during this study.

Introduced fish species include the bluespotted sunfish and the common carp. A small number of bluespotted sunfish were inadvertently released in the river near the Interstate 55 bridge in Madison County, and they established a breeding population (Peterson and Ross 1987). These fish have not spread from the general area in which they were released. The common carp probably entered the river by way of the Mississippi River confluence and now are found throughout the system.

Three species of fish found in the Big Black River have received special attention in other areas and are on conservation status lists. The blue sucker is considered rare though widespread in Mississippi and has been placed on the American Fisheries Society list of species of special concern. The paddlefish, although common in the Big Black River, is regarded by the American Fisheries Society to warrant special concern. The northern madtom is listed by the Mississippi Department of Wildlife, Fisheries, and Parks as rare because of its disjunct distribution pattern. In addition, the Big Black River is

Table 1. Fish taxa of the Big Black River System (from Ross and Brennemen 1991).

Family Species	Common name
Petromyzontidae	
Ichthyomyzon gagei	Southern brook lamprey
Lampetra aepyptera	Least brook lamprey
Polyodontidae	
Polyodon spathula	Paddlefish
Lepisosteidae	
Lepisosteus oculatus	Spotted gar
L. platostomus	Shortnose gar
Amiidae	
Amia calva	Bowfin
Anguillidae	
Anguilla rostrata	American eel
Clupeidae	
Dorosoma cepedianum	Gizzard shad
D. petenense	Threadfin shad
Esocidae	
Esox americanus americanus	redfin pickerel
E. niger	chain pickerel
Cyprinidae	
Campostoma anomalum	Central stoneroller
Cyprinella camura	Bluntface shiner
C. lutrensis	Red shiner
C. venusta	Blacktail shiner
Cyprinus carpio	Common carp
Hybognathus hayi	Cypress minnow
H. nuchalis	Mississippi silvery minnow
Luxilus chrysocephalus	Striped shiner
Lythrurus fumeus	Ribbon shiner
L. roseipinnis	Cherryfin shiner
L. umbratilis	Redfin shiner
Macrhybopsis aestivalis	Speckled chub
M. storeriana	Silver chub
Nocomis leptocephalus	Bluehead chub
Notemigonus crysoleucas	Golden shiner
Notropis amnis	Pallid shiner
N. atherinoides	Emerald shiner
N. blennius	River shiner
N. buchanani	Ghost shiner
N. longirostris	Longnose shiner
N. maculatus	Taillight shiner
N. sabinae	Sabine shiner
N. shumardi	Silverband shiner
N. texanus	Weed shiner
N. volucellus	Mimic shiner
Opsopoeodus emiliae	Pugnose minnow
Pimephales notatus	Bluntnose minnow
P. vigilax	Bullhead minnow
Semotilus atromaculatus	Creek chub
Catostomidae	
Carpiodes carpio	River carpsucker
C. cyprinus	Quillback
C. velifer	Highfin carpsucker
Cycleptus elongatus	Blue sucker
Castomidae *(continued)*	
Erimyzon oblongus	Creek chubsucker
E. sucetta	Lake chubsucker
Ictiobus bubalus	Smallmouth buffalo
I. cyprinellus	Bigmouth buffalo
I. niger	Black buffalo
Minytrema melanops	Spotted sucker
Moxostoma erythrurum	Golden redhorse
M. poecilurum	Blacktail redhorse
Ictaluridae	
Ameiurus melas	Black bullhead
A. natalis	Yellow bullhead
A. nebulosus	Brown bullhead
Ictalurus furcatus	Blue catfish
I. punctatus	Channel catfish
Noturus gyrinus	Tadpole madtom
N. hildebrandi	Least madtom
N. miurus	Brindled madtom
N. nocturnus	Freckled madtom
N. phaeus	Brown madtom
N. stigmosus	Northern madtom
Pylodictis olivaris	Flathead catfish
Aphredoderidae	
Aphredoderus sayanus	Pirate perch
Cyprinodontidae	
Fundulus blairae	Southern starhead topminnow
F. chrysotus	Golden topminnow
F. dispar	Northern starhead topminnow
F. notatus	Blackstripe topminnow
F. notti	Bayou topminnow
F. olivaceus	Blackspotted topminnow
Poeciliidae	
Gambusia affinis	Western mosquitofish
Atherinidae	
Labidesthes sicculus	Brook silverside
Menidia beryllina	Inland silverside
Percichthyidae	
Morone chrysops	White bass
Centrarchidae	
Centrarchus macropterus	Flier
Elassoma zonatum	Banded pygmy sunfish
Enneacanthus gloriosus	Bluespotted sunfish
Lepomis cyanellus	Green sunfish
L. gulosus	Warmouth
L. humilis	Orangespotted sunfish
L. macrochirus	Bluegill
L. marginatus	Dollar sunfish
L. megalotis	Longear sunfish
L. microlophus	Redear sunfish
L. punctatus	Spotted sunfish
L. symmetricus	Bantam sunfish
Micropterus punctulatus	Spotted bass
M. salmoides	Largemouth bass

Table 1. *Continued.*

Family Species	Common name	Family Species	Common name
Centrarchidae *(continued)*		Percidae *(continued)*	
Pomoxis *annularis*	White crappie	E. *parvipinne*	Goldstripe darter
P. nigromaculatus	Black crappie	*E. proeliare*	Cypress darter
Percidae		*E. stigmaeum*	Speckled darter
		E. swaini	Gulf darter
Ammocrypta beani	Naked sand darter	*E. whipplei*	Redfin darter
A. clara	Western sand darter	*Percina caprodes*	Logperch
A. vivax	Scaly sand darter	*P. maculata*	Blackside darter
Etheostoma asprigene	Mud darter	*P. sciera*	Dusky darter
E. caeruleum	Rainbow darter	*P. shumardi*	River darter
E. chlorosomum	Bluntnose darter	*P. vigil*	Saddleback darter
E. fusiforme	Swamp darter	*Stizostedion canadense*	Sauger
E. gracile	Slough darter	Sciaenidae	
E. histrio	Harlequin darter	*Aplodinotus grunniens*	Freshwater drum
E. lynceum	Brighteye darter		
E. nigrum	Johnny darter		

Table 2. List of species and percentage composition by weight from rotenone sampling, Big Black River 1987.

Species	Weight (kg)	Composition (%)	Species	Weight (kg)	Composition (%)
Smallmouth buffalo	496.10	37.00	Largemouth bass	1.20	0.10
Common carp	241.89	18.00	Black crappie	0.60	0.06
Blue catfish	171.50	13.00	Spotted gar	0.44	0.03
Freshwater drum	132.50	10.20	Threadfin shad	0.45	0.01
Flathead catfish	89.01	6.60	Warmouth	0.19	0.01
Paddlefish	74.41	5.50	Black bullhead	0.10	0.01
Gizzard shad	42.49	3.20	Blacktail shiner	0.16	0.01
Channel catfish	21.50	3.10	Bullhead minnow	0.12	0.01
Bigmouth buffalo	41.10	2.90	Pirate perch	0.02	0.01
Longnose gar	3.00	2.20	Pugnose minnow	0.01	0.01
River carpsucker	19.00	1.40	Blackstripe topminnow	0.01	0.01
White crappie	5.50	0.40	Emerald shiner	0.01	0.01
Bluegill	1.80	0.14	Brown madtom	0.01	0.01
Mirror carp	1.58	0.12	Brook silversides	0.01	0.01
Shortnose gar	1.71	0.12	Weed shiner	0.01	0.01
Longear sunfish	1.30	0.11	Ghost shiner	0.01	0.01
Blue sucker	1.20	0.10			

the only system in Mississippi where the western sand darter has been reported and is represented by only three specimens; it is not a listed species, and it's status should be reevaluated (Ross and Brenneman 1991). Without any established sampling schemes, population trends of these species are unknown.

Invertebrate Composition

Limited invertebrate studies have been conducted in the Big Black River. Insaurralde (1992) collected macroinvertebrates from two areas using driftnets set overnight, and Hartfield and Rummel (1985) surveyed the unionid population of this system by various methods.

Insaurralde (1992) collected and identified 18 insect taxa (Table 4). Insect drift was reported to be 3×10^{-2} insects/m^3 and 5×10^{-3} mg/m^3. Diptera (30.2%), Coleoptera (29.1%), and Trichoptera (28.7%) were the dominant groups. Representatives of Ephemeroptera (6.1%), Megaloptera (0.5%), Hemiptera (0.3%), and Odonata (0.15) also were observed. Freshwater prawns (*Palaemonetes* spp.) and leeches (*Philobdella* spp.) composed the remaining 5%. Functional group classification found 52.4% to be collectors. Collector/predators composed 30.3% and predators 12.4% of the insect taxa collected.

Table 3. Mean catch per unit of effort (fish/h, kg/h) for fish collected with electrofishing in the Big Black River (1988). Standard errors in parentheses.

Species	Fish/h	Kg/h
Smallmouth buffalo	12.8 (2.5)	15.1 (1.7)
Gizzard shad	11.8 (3.5)	3.0 (1.9)
Bluegill	10.5 (4.4)	0.6 (3.4)
Pugnose minnow	6.4 (7.3)	*
Channel catfish	6.0 (3.3)	0.7 (2.4)
Freshwater drum	5.3 (2.1)	1.8 (0.7)
White crappie	5.3 (2.4)	0.6 (1.1)
Weed shiner	5.1 (2.5)	*
Blacktail shiner	4.9 (6.2)	*
Common carp	4.8 (1.6)	8.9 (0.8)
Emerald shiner	3.9 (2.2)	*
Chestnut lamprey	3.7 (0.8)	*
Blue sucker	3.0 (1.2)	5.1 (0.5)
Bigmouth buffalo	2.7 (1.8)	4.6 (2.6)
Largemouth bass	2.6 (3.3)	0.5 (1.7)
Longear sunfish	2.1 (1.3)	*
Spotted gar	2.0 (0.3)	0.2 (0.5)
Warmouth	1.5 (1.2)	*
Longnose gar	1.1 (0.5)	1.3 (0.7)
Spotted bass	1.1 (2.5)	0.1 (1.4)
Bullhead minnow	0.9 (1.1)	*
Silverband shiner	0.8 (0.5)	*
Black crappie	0.8 (2.1)	0.1 (0.9)
Orangespotted sunfish	0.7 (0.3)	*
Green sunfish	0.7 (0.1)	*
Blue catfish	0.5 (3.2)	0.1 (1.2)
Flier	0.2 (0.1)	*

* Denotes a CPUE value of <0.1 kg/h.

Early in this century, 18 species of mussels were found in the river (Hinkley 1906) near Durant in Holmes County. A later statewide survey of unionids performed by Grantham (1969) added no new species to the list compiled by Hinkley. Collections conducted along 321 km of the river in 1980–81 produced 31 species of unionids and the Asian clam (*Corbicula fluminea*; Hartfield and Rummel 1985; Table 5).

Hartfield and Rummel (1985) observed that as the river flowed through the different physiographic regions the makeup of the species changed. They found the greatest diversity to be in the stretch flowing through the Loess Bluff Hills, where eight species were identified. The black clubshell (*Pleurobema curtum*), reported by Hinkley (1906) and Hartfield and Rummel (1985), has been placed on the federal endangered species list and is protected (Stansbury 1976). The Loess Bluff Hills region has been proposed as an outstanding resource water section.

Recreational and Commercial Fisheries

The Big Black River Basin Coordinating Committee (1968) estimated that 373,200 man-days were expended on the river by recreational anglers. The committee projected no change in angling effort through 1980. Heavy and frequent bank and boat angling were anecdotally noted by Coleman (1969). In a statewide survey of recreational anglers (Miranda and Frese 1987), 3.2% of the respondents fished the Big Black River. Fishing activity occurred in all 11 counties in the basin. Personal observations by Skains (1992) indicated that most recreational fishing activity occurred from early spring through early summer. It decreased drastically thereafter because of the difficulty in navigating through numerous log jams during low-flow periods. During low-flow periods, fishing activity centered immediately around access points.

The flathead catfish is one of the most sought game fish in the state (Miranda and Frese 1987; Pugibet 1989), and the Big Black River is noted among local fishers for its flathead catfish fishery. Most of the sportfish harvest is composed of these fish, along with blue catfish and channel catfish (Coleman 1969). Lesser numbers of bluegill, white crappie, and largemouth bass are also harvested.

Trotlines, limb lines, and hand grabbing are the primary methods used to capture catfish. Trotlines and limb lines are fished in the larger eddies and pools and are baited with live sunfish. Hand grabbers normally use overflow areas and tributary streams rather than the mainstem (Jackson et al. 1990), apparently because of the more stable environment afforded by backwater locations. The unstable nature of the river channel (i.e., rising and falling water levels) causes difficulties in structure (hand grabbing boxes) placement and loss of structures because of strong currents.

A limited commercial fishery exists on the river by fishers gaining access from the Mississippi River during high-flow periods (D. Robinson, Mississippi Department of Wildlife, Fisheries, and Parks, personal communication). This fishery is almost nonexistent during summer because of the inability to navigate the stream. Jackson et al. (1990) observed no commercial fishing activity in study reaches at any time.

In 1960, 53 commercial anglers harvested an estimated 90,800 kg of fish from the river (Big Black River Basin Coordinating Committee 1968). Buffalo species composed 56% of the total catch, while flathead catfish contributed 19%. Other species harvested included the common carp (9,500 kg), freshwater drum (4,300 kg), blue catfish and channel catfish (8,400 kg), and paddlefish (450 kg). Commercial fishers used primarily hoopnets (88%) and trotlines (7%).

Current regulations placed on commercial fisheries include minimum length limits on all buffalo species (406 mm TL; 305 mm dressed) and all catfish species (305 mm TL; 229 mm dressed). Commercial harvest of paddlefish or their eggs is prohibited during the period from 1 January through 30 April. Hoopnets are limited to 7.6-cm bar mesh netting, while gillnets and trammel nets must have 10-cm bar mesh or larger.

Table 4. Insect taxa, functional group, and biomass composition in the Big Black River (from Insaurralde 1992).

Taxa	Functional group	Weight (%)
Ephemeroptera		
Baetidae		
Baetis	Collector	5.7
Heptageniidae		
Cinygmula	Collector/ scrapper	0.2
Tricorythidae		
Tricorythodes	Collector	0.2
Donata		
Gomphidae		
Gomphus	Predator	0.1
Hemiptera		
Corixidae	Collector/ predator	0.3
Megaloptera		
Corydalidae		
Chauliodes	Predator	0.2
Corydalus	Predator	0.4
Trichoptera		
Hydroptilidae	Collector	0.1
Hydropsychidae		
Cheumatopsyche	Collector	2.2
Hydropsyche	Collector	25.9
Leptoceridae		
Nectopsyche	Collector	0.5
Coleoptera		
Carabidae	Predator	11.7
Elmidae		
Ancyronyx	Collector	1.5
Stenelmis	Collector	15.9
Diptera		
Chironomidae	Collector/ predator	30.0
Simuliidae		
Prosimulium	Collector	0.2

Modeling

Until recently, little effort was made to integrate fisheries data with physical river data on the Big Black River. Insaurralde (1992) and Skains (1992) worked extensively on the river, but both authors limited the scope of their projects to the flathead catfish. Insaurralde focused on physical parameters as they related to relative estimates of density, stock structures, and growth rates. Skains examined the linear home range and movements of this species as a function of fish density and in-stream features.

Insaurralde (1992) found that while National Aircraft Program imagery was useful in defining general land-use patterns, there were no significant relationships between selected land use pa-

Table 5. Mussel taxa collected and identified from the Big Black River (from Hartfield and Rummel 1985).

Species
Amblema plicata perplicata
Anodonta grandis corpulenta
A. g. grandis
A. imbecillis
Arcidens confragosus
Corbicula fluminea
Elliptio crassidens
Fusconaia cerina
F. ebena
F. flava
Glebula rotundata
Lampsilis ornata
L. ovata luteola
L. radiata hydiana
L. teres anodontoides
Leptodea fragilis
Ligumia subrostrata
Megalonaias nervosa
Obliquaria reflexa
Obovaria jacksoniana
O. subrotunda
O. unicolor
Plagiola lineolata
Plectomerus dombeyanus
Pleurobema curtum
P. rubrum
Potamilis purpuratus
Quadrula apiculata aspera
Q. cylindrica
Q. nodulata
Q. pustulosa pustulosa
Tritogonia verrucosa
Truncilla donaciformis
T. truncata
Uniomerus tetralasmus
Villosa lienos

rameters (i.e., the percentage of land used for agriculture or that remaining as forest) and catch rates or stock structures. However, catch rates were strongly related to successional stages of the riparian vegetation, as estimated from low altitude aerial photography. The percent of old growth forest (>75-years-old) in the riparian zone was positively related to hoopnet catch rates in terms of biomass ($r^2 = 0.77$, $P = 0.04$), while the percentage of young growth (10–15 years old) was negatively related to catch rates in terms of numbers ($r^2 = 0.40$, $P = 0.02$). The number of woody snags per unit area positively influenced proportional stock density (PSD; $r^2 = 0.61$, $P = 0.01$) and relative stock density-preferred (RSD61) values ($r^2 = 0.51$, $P = 0.01$).

Growth rates were associated with river stage (Insaurralde 1992). Growth increments of young flathead catfish (age 1 to age 2) increased with increasing frequency of flooded days and declined as a function of the number of less than half bank full days. The reverse was true for older fish (age ≥ 3). Growth increments for these fish were positively related to the number of less than half bank full days and negatively associated with the number of greater than half bank full days.

Skains (1992) chose to examine the effects of associated fish assemblages and habitat characteristics on flathead catfish home range and movement. The linear length of the home range was negatively related to the relative abundance of forage fish; that is, as forage abundance increased the size of the home range decreased. Home range was positively associated with snag densities, flathead catfish densities, and the variance of stream reach depth ($R^2 = 0.88$, $P = 0.037$). Forage fish densities were positively correlated with habitat characteristics.

Ross and Baker (1983) reported on the floodplain use of fish in response to periodic flooding in a small stream in south-central Mississippi. To date, this aspect of fish behavior has not been studied in the Big Black River. Further, no research has been conducted on the influence of tributaries or the Mississippi River on fish assemblages in the Big Black River.

Conclusions

Water quality and habitat modifications affect production in warmwater streams. Point source contaminants of municipal or industrial origin can alter the water quality of the receiving stream. Discharges from sewage treatment facilities may reduce dissolved oxygen concentrations and increase nutrient levels and pathogen counts (Felley 1992). The concentration of chlorine used in secondary sewage treatment may affect species diversity, not only from the toxicity of the chlorine but also by increasing the persistence of ammonia downstream (Lewis et al. 1980). Alterations in the riparian zone may result in increased turbidity and

siltation (Felley 1992). Primary productivity from allochthonous processes, important in low-order streams (Benfield 1980; Vannote et al. 1980), may be disrupted because of decreased quality and quantity of the leaf litter (Insaurralde 1992). Channel modification can have drastic effects, such as changes in flow patterns and flood cycles (Felley 1992), alterations in pool–riffle sequences and increased bank erosion (Fajen 1980), and reduction in density and diversity of the aquatic inhabitants (Woods and Griswald 1980). Because woody debris (snags) is positively associated with the stability and density of macroinvertebrates (Angermeier and Karr 1984; Benke et al. 1985) and fish (Insaurralde 1992; Skains 1992), removal of the structures would negatively affect production.

Field data indicate that a rich, diverse aquatic community exists in the Big Black River. The previously mentioned factors probably do not affect the system to any great degree. Municipal and industrial contaminants affect the smaller tributary streams. While these discharges are great enough to result in partially supporting a Mississippi Department of Environmental Quality fish and wildlife use designation, water quality parameters in the tributaries are within acceptable ranges for fish production. The riparian zone is highly vegetated and provides sufficient leaf litter to power allochthonous production. The quality of this area, in terms of successional stage age, is adequate in supplying large, stable snags. No large-scale channel modifications have been undertaken in the past 50 years, so the system has probably recovered. System functions (e.g., nutrient and flood cycles and snag formation) presumably are in a state of dynamic equilibrium.

No current data are available directly relating to commercial or sportfish harvest, and there are no requirements for commercial fishers to report their harvest. However, the habitat quality of the basin and work by Jackson et al. (1990) indicate that the river would provide superb fishing opportunities, particularly for flathead catfish. Two primary factors limit exploitation of this resource. First, limited access points exist along the main channel. Second, navigation is difficult during summer and fall because of numerous snags and expanses of shallow water. These two factors, though limiting the exploitation of the fishery resource, are also somewhat responsible for the present health of the stream. Increasing the number of access points would increase fishing opportunities, though navigation would remain difficult. Increasing access may result in locally depressed fish stocks, particularly flathead catfish. However, Skains (1992) felt that sufficient expanses of lightly exploited areas would exist to replenish depleted stocks.

Relative to the goals of the Mississippi Interstate Cooperative Resource Agreement, the main focus of this report is to define management options that may assist other agencies in the basin. Fortunately for the Big Black River, there seems to be no pressing need to formulate recovery strategies. Currently, only statewide harvest regulations are in place. It may be beneficial to identify factors that help maintain this system.

First, the mainstem of the river has not been altered for the past 50 years. Further, no dams restrict river discharge, and adequate buffer zones exist between the river and agricultural areas. The hydrologic cycle and nutrient transport processes probably approximate those of historic times. This tends to lend credence to the concept that a modified system can recover if given time.

Second, the riparian zone is largely intact, probably because the basin provides excellent hunting opportunities for white-tailed deer, turkey, and squirrels, game animals that are inseparably linked to their habitat. Hunting leases are a valuable commodity, and landowners actively manage their bottomland hardwoods. For whatever reason, the riparian vegetation seems to provide sufficient leaf litter and woody debris (snags) to maintain aquatic stocks.

Finally, there is little urban or industrial development within the basin. While this may be of little value to systems located in highly populated areas, pollution abatement programs may be developed to reduce impacts on affected streams.

These points lend themselves to further areas of research. While our agency does not have fisheries data on the Big Black River before channel work, agencies in other states may have historic and current data on similar situations in comparable systems. Examining species composition and population trends over time may reveal the length of time necessary for a stream to recover. Further research also is warranted on the composition of the riparian zone and its effects on fish production. Relative to successional stages, at what point does young vegetation become critical in terms of leaf litter and snag production? In basins where forests are managed with diverse goals, is it possible to create a patchwork of young and old growth and still maintain the integrity of the system?

Outlook

The future of the Big Black River is bright. There are no current or forecasted plans for channel modifications. Landowners probably will maintain their bottomlands as the value of hunting leases escalates. The Mississippi Department of Environmental Quality will continue to ensure the quality of the water. Finally, changing the flathead catfish from a nongame gross fish to a sportfish is being discussed. As access to the river is improved, this change in status should protect this fish from over-exploitation.

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The Arkansas River—A Changing River

by

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Abstract. The Arkansas River originates in the mountains of Colorado, east of Leadville, at an elevation of 3,659 m above mean sea level. The river winds through Colorado, Kansas, Oklahoma, and Arkansas, a distance of 2,333 km. The total catchment area of the Arkansas River is 414,368 km^2. Construction of the McClellan-Kerr Navigation system began in 1957 and has made the Arkansas River navigable for 726 km through the construction of 17 locks and dams. Thirteen tributary lakes are located within the system; eleven of these are in Oklahoma. The Arkansas River has seven mainstem reservoirs, including two in Colorado. These mainstem reservoirs are typically more fertile than most of the tributary reservoirs. Major factors influencing fisheries resources are regulated discharges and associated water level fluctuations, turbidity and silt load, loss of nursery areas, point and nonpoint source pollution, and urban and industrial development. Fish populations inhabiting the lower Arkansas River are warmwater species consisting mainly of clupeids, catostomids, centrachids, ictalurids, cyprinids, and temperate basses. Resource agencies should work with the U.S. Army Corps of Engineers to develop a master plan to benefit riverine aquatic resources. The plan should include recommendations for water level management and flow rates. Solutions and compromises that will protect and enhance the river's important fishery resources should be derived to protect against further degradation of this valuable water resource.

The Arkansas River is thought to have formed in the Miocene, when highland streams south of the glacial boundary of the Missouri River basin cut headward to capture other drainage basins of the plains.

The Arkansas River receives snowmelt from the eastern slope of the Continental Divide near Leadville, Colorado, at an elevation of 3,659 m above mean sea level (msl). The river flows eastward through Colorado and receives drainage from five physiographic provinces, including the Coastal Plain, Interior Highlands, Central Lowlands, Great Plains, and Rocky Mountains (Cross et al. 1986). The river crosses Colorado, Kansas, Oklahoma, and Arkansas, a distance of 2,339 km, before emptying into the Mississippi River. The catchment area is 414,368 km^2 (Table 1; Fig. 1).

Basin Geography

The fertile Arkansas River valley historically supported large tracts of cottonwood trees and abundant wildlife in Colorado. The river enters Kansas at an elevation of 1,064 m msl and drops and average of 3.2 m/km until it reaches Great Bend, Kansas. The river channel flowing through Kansas was wide (400 m), straight, and very shallow (0.3–1 m) before development (Tomelleri 1984). Most high flows were influenced by snowmelt in Colorado. Flows exceeding 3,048 m^3/s passed through western Kansas in May and June. Channel width and extremely erodible shoreline prevented the river from overflowing its banks.

The Arkansas was a "losing" stream across most of eastern Colorado and western Kansas during

Table 1. Major tributary streams of the Arkansas River and states where originating.[a]

Colorado	
Huerfano River	Fountain Creek
Four Mile Creek	Big Sandy Creek
Purgatoire River	Horse Creek
Rush Creek	
New Mexico and Texas	
Canadian River[a]	
Kansas	
Pawnee River	Walnut Creek
Spring River	Rattlesnake Creek
Cow Creek	Ninnescah River
Chikaskia River	Walnut River
Neosho River[a]	Caney River[a]
Verdigris River[a]	Salt Fork River
Elk River	Cimarron River[a]
Cottonwood River	Medicine Lodge River[a]
Oklahoma	
North Canadian River	Illinois River
Poteau River	Canadian River
Cimarron River	Grand (Neosho) River
Salt Fork River	Caney River
Deep Fork of Canadian River	Verdigris River
Arkansas	
Big Piney Creek	Fourche La Fave River
East Fork Cadron Creek	Illinois Bayou
Lee Creek	Little Maumelle River
Maumelle River	Mulberry River
Palarm Creek	Petit Jean River
Point Remove Creek	Big Bayou Meto
Little Bayou Meto	Plum Bayou
Pennington Bayou	

[a] Enters Arkansas River in Oklahoma.

high flows. Much of the water entered the sandy alluvium of the river valley. However, during low flows shallow aquifers entered the river making it a "gaining" stream.

Before 1910, peak annual rates of discharge at U.S. Geological Survey gauging stations on the river varied from 2,927 to 26,524 m^3/s at Syracuse, Kansas; 3,506 to 5,976 m^3/s at Dodge City; and 732 to 11,890 m^3/s at Wichita (Cross et al. 1985). Fluctuating flows and a highly erodible floodplain combined to create a turbid, dynamic system of bankline erosion at one location and deposition of material in the streambed at another. High dissolved solids were common during summer low flows from the wide, shallow streambed. Isolated storms in tributary drainages increased turbidity during low flows and kept soil particles suspended in the water column (Cross et al. 1985). In the period 1904–42, river flows greater than 229 m^3/s occurred 10% of the time, and flows of 1.5 m^3/s occurred 90% of the time.

Precipitation varies from 37.5 cm in western Kansas to 100 cm in the eastern part of the state. Average annual temperature was 14° C. Three physiographic regions are crossed in Kansas. The western two-thirds of the basin is in the High Plains region, which is flat and gently sloping topography with silt-loam, soils and some aquifers. The Dissected Plains region encompasses the eastern one-third of the basin. It is characterized by hilly terrain with silty clay soils or silty loams, which are subject to erosion. The Arkansas Valley Lowlands region near the channel contains loose sand, sandy silt, silt loam, and alluvial soils with frequent aquifers to 47 m depth (Layher et al. 1978). Historically, vegetation was composed of native prairie communities including bluestem–grama, bluestem sand, and cedar hill prairies.

The Arkansas River enters Oklahoma from Kansas in north–central Oklahoma and flows through Permian Age Central Reddish Prairie and Rangeland soils until it reaches the city of Tulsa, where it flows in a southeasterly direction across the Eastern Cherokee Prairies composed of dark clayey subsoils under tall grasses. The western Oklahoma tributaries contribute dissolved salts and gypsum to the Arkansas River left millions of years ago by a shallow sea. These deposits are the most abundant source of dissolved solids and chlorides. East of Tulsa, the Cookson and Ozark Hills of the Ozark Highlands contribute water of excellent quality from limestone deposits. Before development the average river flow at Tulsa was 1,998 m^3/s, with minimum flows of 8.2 m^3/s and high flows of 93,598 m^3/s (Table 2).

The Arkansas River enters Arkansas near Fort Smith and crosses the state diagonally northwest to southeast, a distance of 500 km. The drainage area is 28,490 km^2. The river traverses several physiographic regions in Arkansas, including the Arkansas River valley, a deep synclinal trough lying between the Ozark Mountains to the north and the Ouachita Mountains to the south. Surface rock in the valley is primarily sandstone and shale, with alluvium along the river. Vegetation varies from shortleaf pine and upland hardwoods to bottomland hardwoods. The river crosses a portion of the Ouachita Mountains nearly halfway through Arkansas and then enters the Gulf Coastal Plain division of the Mississippi Alluvial Plain. This area was formed by alluvial deposition of river-washed material, especially silt. It is a lowland area of

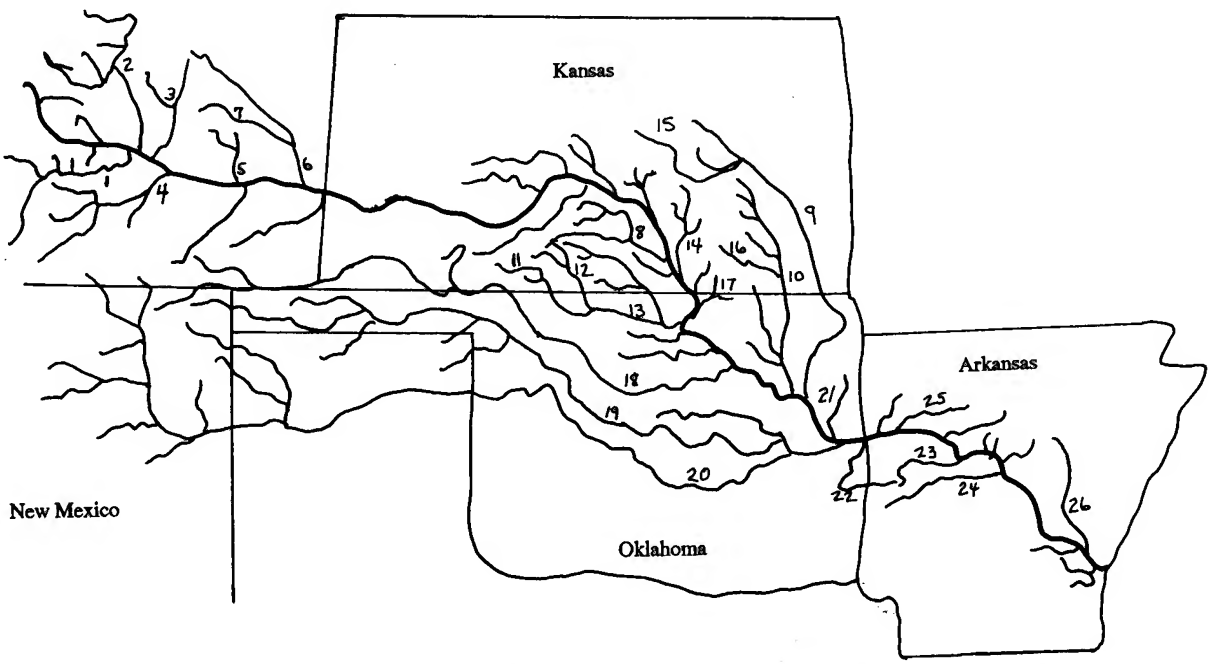

Fig. 1. Arkansas River basin drainage: 1. Huerfano River, 2. Four Mile Creek, 3. Fountain Creek, 4. Purgatoire River, 5. Horse Creek, 6. Big Sandy Creek, 7. Rush Creek, 8. Ninnescah River, 9. Neosho (Grand) River, 10. Verdigris River, 11. Salt Fork River, 12. Medicine Lodge River, 13. Chikaskia River, 14. Walnut River, 15. Cottonwood River, 16. Elk River, 17. Caney River, 18. Cimarron River, 19. N. Canadian River, 20. Canadian River, 21. Illinois River, 22. Poteau River, 23. Petit Jean River, 24. Fourche La Fave, 25. Mulberry River, 26. Bayou Meto.

slightly rolling bottomlands, and upland areas consist of terraces formed during the Pleistocene. Vegetation consists of bald cypress and tupelo in the swampy lowland areas and loblolly pine and bottomland hardwoods in the upland areas (Arkansas Department of Planning 1974).

Basin Development

Few settlements existed upstream from Arkansas Post (southeast Arkansas) until light draft steamboats were used on the river in 1822. Low water, numerous shoals, and snags prevented navigation upriver. Early work in Arkansas and Oklahoma consisted mainly of removal of snags for navigation by river boats. Low water often prevented that. The first brush and stone dike was built by the U.S. Army Corps of Engineers near Fort Smith in 1878.

Diverse and abundant mineral deposits in the Rocky Mountains near the Arkansas River headwaters stimulated mining interests. Mining for gold, copper, zinc, and, later, molybdenum exposed the Arkansas River to the refuse of these activities. Because of these mining activities, the river was never as protected as most Colorado high country streams and suffered greatly from the refuse of these activities. The river valley beyond the moun-

Table 2. Historic high and low flows (m^3/s) in the Arkansas River mainstem.

Location	Maximum	Date	Minimum	Date	Average
Tulsa	93,598	October 1986	8.2	1956, before Keystone Dam	1,998
				1956, after Keystone Dam	2,399
L&D 13	259,146	May 1943	0	1975,81,87,89	10,006
L&D 10	208,232	May 1943	12.2	1975,81,87,89	11,305
L&D 6	163,415	May 1943	4.3	1978	12,902

tains was very fertile, and agriculture development in Colorado began almost as early as mining. The question of water rights became so important in 1886 that Colorado was forced to adopt a "first come, first served" basis for water use (Madsen 1982). Agricultural irrigation rights became the future for the Arkansas River in Colorado. Irrigation associations built reservoirs to hold early spring flows for diversion to agricultural projects. Disputes over water rights became such a problem that federal reservoirs were built. John Martin Reservoir, near Lamar, Colorado, was constructed in 1942. It covered 3,239 ha. Agriculture and agriculture-related developments increased dramatically below John Martin Reservoir at an average rate of 12.1 ha/km and as high as 21.5 ha/km. Increased demands for irrigation of agricultural farmland in Colorado's Arkansas River valley led to an over-appropriation of water, and the river began to dry up below John Martin Reservoir. Colorado built Pueblo Reservoir in 1975; it had a surface area of 1,881 ha. This reservoir upstream from John Martin Reservoir, plus increased use of wells in Kansas and Colorado, led to further reduction in total discharge of water in the Arkansas River. Discharge rates decreased in frequency to only one-fourth to one-tenth the rates before impoundment (Cross and Moss 1987).

The river channel decreased in area by 50%; the greatest decreases occurred below the reservoir in the lower elevations. Agriculture encroached into the floodplain. Large trees declined markedly as the combination of a deeper, narrower channel maintained by reservoir releases and dense stands of tamarisk reduced the opportunity for the regeneration of cottonwoods (Snyder and Miller 1991). Irrigation diversions were also used in Kansas owing to decreased flow in the Arkansas River due to heavy appropriations in Colorado and increased agricultural demands. Thus, the river channel in parts of Kansas was similarly reduced to half of its original width because of these irrigation diversions. The introduction of center pivot sprinkler irrigation techniques in Kansas resulted in a decline of ground water, which caused flow in the Arkansas River to disappear into the channel alluvium. Flows declined so much that flows of 0.3 m^3/s occur only 10% of the time in the middle section of the river, and flows of greater than 3 m^3/s occur only 50% of the time in the Great Bend Area.

River flow rates moderated after the construction of John Martin Reservoir. High flows decreased, and flows of 10% frequency dropped from 28 m^3/s to 12.7 m^3/s. Flows of 75% frequency increased from 0.48 to 1.76 m^3/s, and flows of 90% frequency doubled (Cross and Moss 1987).

Natural flooding continued in Arkansas and Oklahoma, thus fueling momentum for flood control development on the Arkansas River system. A 1927 flood left half of Arkansas under water, with flood losses exceeding $43 million. The Rivers and Harbors Act of 1946 authorized development of the Arkansas River and its tributaries for navigation, flood control, hydroelectric power, and other purposes. However, no funds were appropriated until 1949. Initial funding was used to stabilize riverbanks at critical points along the river.

The Arkansas River carried large amounts of sediment, amounting to an average annual load of 95.5 million metric tons at Little Rock. Upstream reservoirs would have to be built in Oklahoma to trap silt, to hold back floodwaters, and to release sufficient water during periods of low flow. Keystone Dam on the Arkansas River and Eufala Dam on the Canadian and Deep Fork rivers were completed in 1964. Locks and dams to overcome the 128 m difference in altitude and provide a reliable commercial navigation channel from the mouth of the Arkansas to the head of navigation at Catoosa, Oklahoma, were built.

Dardanelle Lock and Dam, the first structure on the river in Arkansas, was begun in 1959. All locks and dams in Arkansas were started by 1966, and all in Oklahoma were begun in 1968.

Navigation System Operation

The primary purposes of the McClellan-Kerr Navigation System (Arkansas River) are navigation, hydroelectric power generation, flood control, fish and wildlife habitat and environmental enhancement, water supply, and channel stabilization. Flood control is provided by 50 upstream dams throughout the basin (Fig. 2). Hydroelectric power is generated at six of the tributary lakes (Oklahoma) and at four mainstream dams, with an average energy potential from these 10 power plants of over 3,000 megawatts (Table 3).

The navigation channel begins at the confluence of the White and Mississippi rivers in southeast Arkansas. The first 6.2 km are navigated on the White River, and then barge traffic transfers to the Arkansas River. The system crosses Arkansas in a northwesterly direction into Oklahoma. The navigation system goes to the Verdigris River

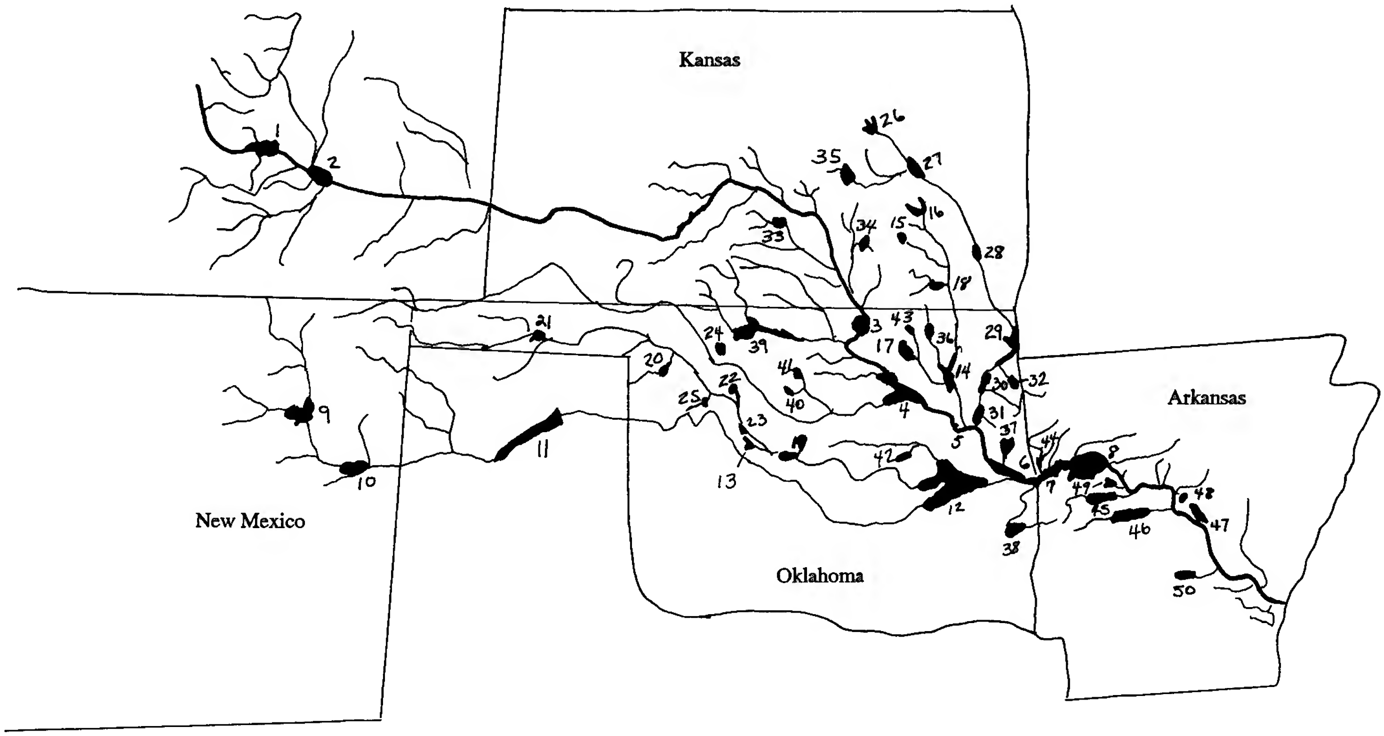

Fig. 2. Major lakes in the Arkansas River basin. Numbers refer to location.

Project	Size (ha)	Tributary	State	Project	Size (ha)	Tributary	State
1. Pueblo	1,215	Ark. River	Co.	29. Grand Lake	18,826	Grand (Neosho) River	Ok.
2. John Martin	1,619	"	Co.				
3. Kaw	6,883	"	Ok.	30. Hudson	4,413	"	Ok.
4. Keystone	10,526	" & Cimarron River	Ok.	31. Fort Gibson	8,057	"	Ok.
5. Webbers Falls	4,200	"	Ok.	32. Spavinaw	641	"	Ok.
6. Kerr	17,004	"	Ok.	33. Cheney	3,862	Ninnescah River	Ks.
7. Ozark	4,291	"	Ar.	34. El Dorado	3,239	Walnut River	Ks.
8. Dardanelle	13,887	"	Ar.	35. Marion	3,664	Cottonwood River	Ks.
9. Ute	3,320	Canadian River	N.M.	36. Hulah	1,457	Caney River	Ok.
10. Conchas	3,644	"	N.M.	37. Tenkiller	5,223	Illinois River	Ok.
11. Meredith	6,682	"	Tx.	38. Wister	1,619	Poteau River	Ok.
12. Eufala	41,376	" & N. Canadian	Ok.	39. Great Salt Plains	3,518	Salt Fork River	Ok.
13. Thunderbird	2,457	Canadian River	Ok.				
14. Oologah	11,943	Verdigris River	Ok.	40. Carl Blackwell	1,364	Trib. to Cimarron River	Ok.
15. Toronto	1,134	"	Ks.				
16. Fall River	992	Verdigris trib/ Fall River	Ks.	41. McMurtry	468	"	Ok.
				42. Okmulgee	291	Deep Fork of Can. River	Ok.
17. Skiatook	4,126	Verdigris trib.	Ok.				
18. Elk City	1,781	Verdigris trib./ Elk River	Ks.	43. Birch	461	Trib. to Arkansas River	Ok.
19. Canton	3,202	N. Canadian	Ok.	44. Lee Creek	243	Lee Creek	Ar.
20. Fort Supply	737	N. Canadian trib.	Ok.	45. Blue Mountain	1,178	Petit Jean River	Ar.
21. Optima	2,162	"	Ok.	46. Nimrod	1,437	Fourche La Fave River	Ar.
22. Overholser	688	"	Ok.				
23. Shawnee	878	"	Ok.	47. Conway	2,712	Palarm Creek	Ar.
24. Arcadia	737	"	Ok.	48. Overcup	415	Trib. to Arkansas River	Ar.
25. Hefner	1,045	"	Ok.				
26. Council Grove	1,328	Neosho River	Ks.	49. Atkins	304	Trib. to Arkansas River	Ar.
27. John Redmond	3,806	"	Ks.				
28. Wolf Creek	2,024	"	Ks.	50. Maumelle	3,603	Maumelle River	Ar.

Table 3. Description of locks and dams in Arkansas River navigation system.[a]

L&D no.	Upper pool[b]	Name	Date completed	River km	Km shoreline	Con. pool (ha)	River	Gen. Capacity
1	43	Norrel	1967	6.4	4	23	White	
2	49	Pendleton	1967	25.1	60	1,737	Arkansas	
3	55	Swan Lake	1968	30.6	22	602	Arkansas	
4	60	Pine Bluff	1968	40.9	36	931	Arkansas	
5	65	White Bluff	1968	53.4	31	1,095	Arkansas	
6	70	Terry	1969	67	27	1,907	Arkansas	33,000 kw
7	76	Murray	1968	77.7	105	3,927	Arkansas	
8	81	Toad Suck	1969	93	29	1,672	Arkansas	
9	87	Ormond	1969	107.5	62	1,988	Arkansas	40,000 kw
10	103	Dardanelle	1969	127.4	199	13,887	Arkansas	124,000 kw
12	113	Ozark	1969	159.2	107	4,291	Arkansas	100,000 kw
13	120	Barling	1969	181.5	74	2,308	Arkansas	30,000 kw
14	125	Mayo	1971	195.3	31	607	Arkansas	
15	140	Kerr	1970	204.6	155	17,004	Arkansas	110,000 kw
16	149	Webbers Falls	1970	229.0	97	4,049	Verdigris	60,000 kw
17	156	Chocteau	1970	248.9	31	207	Verdigris	
18	162	Newt Graham	1970	261.4	48	216	Verdigris	

[a] The navigation system consists of 17 single chamber locks—33.5 m wide and 183 m long. The navigation channel is a minimum 77 m wide on the Arkansas River and 45.7 m wide on the Verdigris River, with a channel depth of 2.7 m maintained.
[b] Upper Pool level in meters above mean sea level (msl) elevations.

at Muskogee, Oklahoma (river km [rkm] 637), and ends 80 km upstream at the Port of Catoosa (Table 3; Fig. 3). The system was designed to transport 31.8 million metric tons of barge cargo annually. After deducting local hauls of rock, sand, and gravel tonnage, a total of 8.3 million metric tons were transported in Arkansas and 3.9 million metric tons in Oklahoma in 1991. Flows of over 2,800 m^3/s, which occur annually in spring and sometimes winter, cause towboats to reduce tow size. These high flows also cause shoaling, which can reduce navigation channel depth, thus preventing barge traffic by larger tows. Dredging is necessary when shoaling occurs in the navigation channel.

River Aquatic Resources

Forty-two species of fish are found in the Arkansas River in Colorado. Twenty-five species have been introduced, and five species are considered threatened or of special concern: cutthroat trout

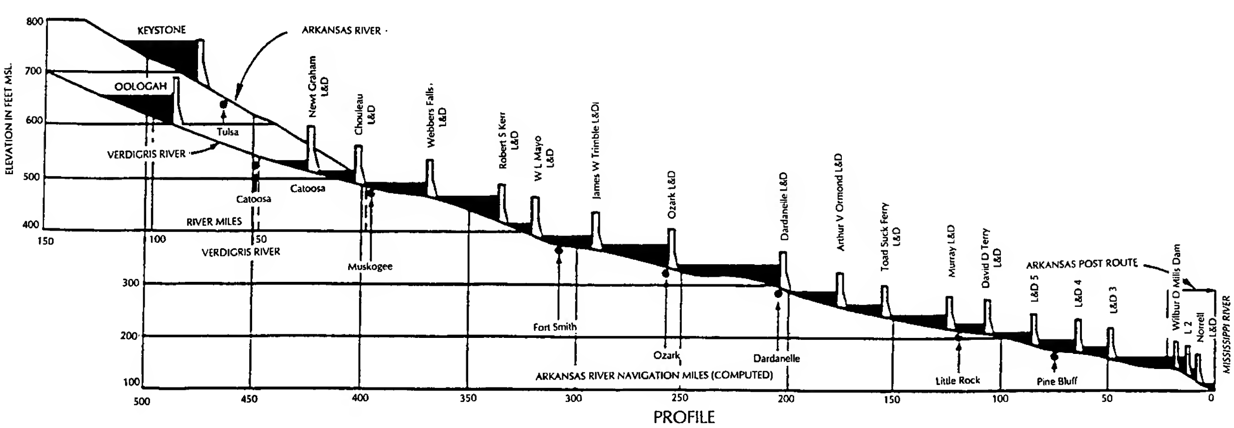

Fig. 3. Arkansas River Navigation System Pools (U.S. Corps of Engineers 1989).

(*Oncorhynchus clarki*), bigmouth shiner (*Notropis dorsalis*), southern redbelly dace (*Phoxinus erythrogaster*), Arkansas darter (*Etheostoma cragini*), and American eel (*Anguilla rostrata*). One species, Arkansas River speckled chub (*Macrhybopsis aestivalis*), has been extirpated from the river.

Fifty-four species of fish have been reported in the mainstem Arkansas River in Kansas. Seven species have been introduced, and four species have been extirpated from the river in Kansas: bluntface shiner (*Cyprinella camura*), Arkansas River shiner (*Notropis girardi*), southern redbelly dace, and American eel.

Eighty-six species of fish have been reported in the mainstem Arkansas River in Oklahoma. Of this number 10 species have been introduced, and three species are currently being considered for placement on the federal threatened and endangered list: Arkansas speckled chub, Arkansas River shiner, and blue sucker (*Cycleptus elongatus*).

Arkansas has 108 species of fish in the mainstem Arkansas River. Forty-six species were introduced as a result of the navigation system, and 40 species were indigenous to the system. No endangered species are listed, and four species have been extirpated from the mainstem: plains minnow (*Hybognathus placitus*), Arkansas River shiner, suckermouth minnow (*Phenacobius mirabilis*), and speckled chub (Buchanan 1976; Table 4).

An average of 303 kg/ha of biomass was determined on the upper portion of the Arkansas River in Kansas on samples from 6 sites, and an average of 102.8 kg/ha was determined from 12 sites on the lower portion below Great Bend, Kansas (Layher 1978). Sportfish consisted of largemouth bass, white crappie, bluegill, channel catfish, and flathead catfish on the upper portion and these species plus spotted bass on the lower portion.

Oklahoma uses a standard sampling procedure to sample fish populations: spring electrofishing, summer shoreline seining, and fall gillnetting and trapnetting. Rotenone sampling has been discontinued; however, averages of the last samples showed Kerr Reservoir (Pool 15) with 357.6 kg/ha and Webber Falls (Pool 16) with 481 kg/ha. Clupeids composed about 40% and commercial species 30% of the total by weight.

Arkansas uses a standard sampling procedure. Waters are sampled using shoreline seining, and rotenone sampling of coves in summer with a 2-day pickup. Spring electrofishing, gillnetting, and trapnetting are conducted on selected pools. Parts of the Arkansas River being sampled using rotenone are Pools 13, 12, 10, and 2. Merrisach Lake (located within Pool 2) has been sampled 2 of the last 4 years. Pool 13 is sampled at one location, Pool 12 is sampled at two sites, and Dardanelle is sampled at three different locations. Pool 13 has yielded an average of 605 kg/ha (26% sportfish and 44% commercial fish), Ozark (Pool 12) 1,065.55 kg/ha (20% sportfish and 29% commercial fish); and Dardanelle (Pool 10) an average of 693 kg/ha (17% sportfish and 43% commercial fish). Merrisach Lake has yielded an average of 1,146.5 kg/ha (48% sportfish and 17% commercial species; Table 5). The Arkansas River is one of the most productive bodies of water in the State of Arkansas for sportfishing and commercial fishing activities. A 1987 study conservatively estimated 840,000 angler fishing trips per year, with fishermen spending \$1.62 million on the Arkansas River (Arkansas Soil and Water Commission 1988, unpublished report). The U.S. Army Corps of Engineers estimated total fishing usage in 1992 at 3,962,616 persons, with approximately 130 fishing tournaments annually and \$220,000 spent at a single state event. Larger tournaments bring approximately \$1.3 million annually (U.S. Army Corps of Engineers 1992).

Commercial fishing on the Arkansas River is limited to only the State of Arkansas. The river there has been open to commercial fishing since 1971. Commercial harvest records have been kept since 1976. Commercial species include catfish, buffalo, drum, carp, gar, sucker, carpsucker, white amur, paddlefish, sturgeon, and bowfin. During the early 1970's commercial fishers kept all commercial species for sale. During the last 10 years, however, buffalo and catfish have become the primary target species. The total commercial harvest in 1987–88 was 2,283,466 kg (41% buffalo and 48% catfish) with a value of \$2 million (Farwick 1988).

Commercial mussel harvest in Kansas occurs mainly on Arkansas River tributaries (Neosho, Verdigris, and Walnut rivers). Commercial mussel harvest in Kansas increased in the 1970's and 1980's and is a matter of some concern, with further regulation anticipated (F. B. Cross, University of Kansas, Lawrence, personal communication). The Arkansas River in Arkansas is open to commercial harvest of mussel shells. Commercial shellers harvested 38,675 kg in 1990 and 17,842 kg in 1991. Maple leaf (86%), three ridges (2%) and washboards (9%) composed most of the shells taken. The Arkansas River accounted for 12% of the statewide harvest of mussel shells in

Table 4. Fish species found in the mainstem Arkansas River in Kansas, Oklahoma, and Arkansas.

Species	Colorado	Kansas	Oklahoma	Arkansas
Chestnut lamprey, *Icthyomyzon castaneus*			X	X
Paddlefish, *Polyodon spathula*		X	X	1
Shovelnose sturgeon, *Scaphirhynchus platorynchus*		X	X	1
Bowfin, *Amia calva*			X	X
Spotted gar, *Lepisosteus oculatus*			X	X
Longnose gar, *L. osseus*		X	X	X
Shortnose gar, *L. platostomus*		X	X	X
Alligator gar, *Atractosteus spatula*			X	1
Alabama shad, *Alosa alabamae*			X	
Skipjack herring, *A.chrysochloris*			X	X
Gizzard shad, *Dorosoma cepedianum*	3	X	X	X
Threadfin shad, *D. petenense*			3	3
Cutthroat trout, *Oncorhynchus clarki*	1			
Rainbow trout, *O. mykiss*	3		3	3
Brown trout, *Salmo trutta*	3			
Brook trout, *Salvelinus fontinalis*	3			
Grass pickerel, *Esox americanus vermiculatus*			3	X
Chain pickerel, *E. niger*				X
Goldeye, *Hiodon alosoides*		1	X	X
Mooneye, *H. tergisus*				X
Central stoneroller, *Campostoma anomalum*	X	X	X	X
Goldfish, *Carassius auratus*	3	3		3
Grass carp, *Ctenopharyngodon idella*	3			3
Common carp, *Cyprinus carpio*	3	3	3	3
Plains minnow, *Hybognathus placitus*		1	X	2
Cypress minnow, *H. hayi*				X
Mississippi silvery minnow, *H. nuchalis*				X
Pallid shiner, *Notropis amnis*				1
Speckled chub, *Macrhybopsis aestivalis*	2	1	1	2
Flathead chub, *Platygobio gracilis*	X	1		
Silver chub, *M. storeriana*			X	X
Silver carp, *Hypophthalmichthys molitrix*				3
Bighead carp, *H. nobilis*	3			
Golden shiner, *Notemigonus crysoleucas*	3	X	X	3
Bluntface shiner, *Cyprinella camura*		2		
Red shiner, *C. lutrensis*		X	X	
Blacktail shiner, *C. venusta*				X
Steelcolor shiner, *C. whipplei*				X
Striped shiner, *Luxilus chrysocephalus*				X
Cardinal shiner, *L. cardinalis*			X	
Ribbon shiner, *Lythrurus fumeus*			X	X
Redfin shiner, *L. umbratilis*		X	X	X
Emerald shiner, *Notropis atherinoides*		X	X	X
Red River shiner, *N. bairdi*		X	X	
River shiner, *N. blennius*		1	X	X
Bigeye shiner, *N. boops*			X	X
Ghost shiner, *N. buchanani*			X	X
Ironcolor shiner, *N. chalybaeus*				X
Bigmouth shiner, *N. dorsalis*	3			
Arkansas River shiner, *N. girardi*		2	1	2
Sand shiner, *N. stramineus*	X	X	X	
Silverband shiner, *N. shumardi*			X	X
Mimic shiner, *N. volucellus*			X	X
Pugnose minnow, *Opsopoeodus emiliae*				X
Southern redbelly dace, *Phoxinus erythrogaster*	1	2		
Bluntnose minnow, *Pimephales notatus*		X	X	X

Table 4. *Continued.*

Species	Colorado	Kansas	Oklahoma	Arkansas
Fathead minnow, *P. promelas*	X	X	X	
Slim minnow, *P. tenellus*		1		
Bullhead minnow, *P. vigilax*		X	X	X
Longnose dace, *Rhinichthys cataractae*	X			
Suckermouth minnow, *Phenacobius mirabilis*	X	X	X	2
River carpsucker, *Carpiodes carpio*		X	X	X
Quillback, *C. cyprinus*		3		X
Highfin carpsucker, *C. velifer*			X	X
Longnose sucker, *Catostomus catostomus*	X			
White sucker, *C. commersoni*	X	X		
Creek chub, *Semotilus atromaculatus*	X			
Tench, *Tinca tinca*	3			
Blue sucker, *Cycleptus elongatus*			1	X
Creek chubsucker, *Erimyzon oblongus*			X	
Lake chubsucker, *E. sucetta*			X	
Smallmouth buffalo, *Ictiobus bubalus*		X	X	X
Bigmouth buffalo, *I. cyprinellus*			X	X
Black buffalo, *I. niger*		X	X	X
Spotted sucker, *Minytrema melanops*			X	X
Golden redhorse, *Moxostoma erythrurum*		X	X	X
Shorthead redhorse, *M. macrolepidotum*		X	X	X
River redhorse, *M. carinatum*			X	
American eel, *Anquilla rostrata*		2	X	X
Black bullhead, *Ameiurus melas*	X	X	X	X
Yellow bullhead, *A. natalis*		X	X	X
Blue catfish, *Ictalurus furcatus*	3		X	X
Channel catfish, *I. punctatus*	X	X	X	X
Tadpole madtom, *Noturus gyrinus*				X
Brindled madtom, *N. miurus*				X
Freckled madtom, *N. nocturnus*			X	X
Flathead catfish, *Pylodictis olivaris*		X	X	X
Pirate perch, *Aphredoderus sayanus*				X
Golden topminnow, *Fundulus chrysotus*				X
Starhead topminnow, *F. dispar*				X
Plains killifish, *F. zebrinus*	X			
Blackspotted topminnow, *F. olivaceus*				X
Western mosquitofish, *Gambusia affinis*	3			X
Brook silverside, *Labidesthes sicculus*		X	X	X
Inland silverside, *Menidia beryllina*			3	3
Brook stickleback, *Culaea inconstans*	3			
White bass, *Morone chrysops*	3	3	X	X
Yellow bass, *M. mississippiensis*			X	X
Striped bass, *M. saxatilis*			3	3
Palmetto bass, *M. chrysops* × M. saxatilis			3	3
Flier, *Centrarchus macropterus*			X	X
Green sunfish, *Lepomis cyanellus*	X	X	X	3
Warmouth, *L. gulosus*			X	X
Orangespotted sunfish, *L. humilis*	X	X	X	X
Bluegill, *L. macrochirus*	3	3	X	3
Dollar sunfish, *L. marginatus*				X
Longear sunfish, *L. megalotis*		X	X	X
Redear sunfish, *L. microlophus*		3	3	3
Spotted sunfish, *L. punctatus*				X
Hybrid sunfish, *Lepomis*	3		X	
Smallmouth bass, *Micropterus dolomieu*	3			
Spotted bass, *M. punctulatus*	3	X	X	X

Table 4. *Continued.*

Species	Colorado	Kansas	Oklahoma	Arkansas
Largemouth bass, *M. salmoides*	3	X	X	X
Florida largemouth bass, *M. floridanus*			3	
White crappie, *Pomoxis annularis*	3	X	X	X
Black crappie, *P. nigromaculatus*	3	3	X	X
Banded pigmy sunfish, *Elassoma zonatum*			X	X
Mud darter, *Etheostoma asprigene*				X
Greenside darter, *E. blennioides*				X
Bluntnose darter, *E. chlorosomum*			X	X
Arkansas darter, *E.cragini*	1	1		
Fantail darter, *E. flabellare*				X
Slough darter, *E. gracile*			X	X
Cypress darter, *E. proeliare*				X
Orangethroat darter, *E. spectabile*		1		X
Redfin darter, *E. whipplei*			X	X
Banded darter, *E. zonale*			X	X
Logperch, *Percina caprodes*		1	X	X
Channel darter, *P. copelandi*			X	X
Blackside darter, *P. maculata*				X
Slenderhead darter, *P. phoxocephala*		1	X	1
Dusky darter, *P. sciera*				X
River darter, *P. shumardi*			X	X
Sauger, *Stizostedion canadense*	3		X	X
Walleye, *S. vitreum*	3		3	3
Freshwater drum, *Aplodinotus grunniens*	3	X	X	X
Striped mullet, *Mugil cephalus*				X

1 = Rare, endangered, threatened, or special concern.
2 = Extirpated (mainstem).
3 = Introduced.

1990 and 1991 (Shirley 1990; Farwick 1992). There is little commercial shelling in Oklahoma on the Arkansas River. Fort Gibson Reservoir, located on the Grand River, is the site of most of the shelling that occurs in the basin.

Water Quality

Water quality in the Arkansas River in Kansas is influenced by sedimentation, municipal wastewater, residential waste runoff, irrigation diversions, thermal effluent, and feedlot runoff. In 1975 an average annual sediment load of 2,270,909 metric tons was estimated to enter the river. Surface water diversion for irrigation is a particularly acute problem in reducing instream flows needed to dilute municipal and industrial effluent. The Arkansas River becomes more eutrophic as it flows east across Kansas because of increased municipal use and discharge of wastewater. Reduced flow rate is the limiting water quality factor in Kansas.

Salt deposits near Hutchinson, Kansas, and deposits in Oklahoma raise chloride levels in the Arkansas River. Salt also enters the river system from oil field and refinery operations. Salt concentrations during low flows can be caused from livestock and previous bison waste and evaporation of exposed shallow channels on the high plains. Before installation of the navigation system, chloride levels reached 1,500 mg/L, then declined to 250 mg/L in 1973 and have declined to 128.6 mg/L at Lock and Dam 10 (the station usually having the highest chloride readings). The construction of reservoirs on tributaries to the Arkansas River to control sediment load and for flood control helped slow the influx of chlorides into the river system. Drainages from the Ozark and Ouachita mountains seem to dilute the chloride concentrations (Tables 6 and 7).

In Oklahoma nonpoint source pollution problems include oil- and gas-related brine water, agricultural runoff, urban waste effluent, especially from Tulsa, and urban storm runoff.

Table 5. Biomass and species composition of Arkansas River impoundments in Arkansas and Oklahoma (Arkansas Game and Fish Commission; Oklahoma Department of Wildlife Conservation). N = number of samples.

Pool no.	N	Biomass (kg/ha)	Percent of total *Micropterus*	*Morone*	Ictalurids	Centrachids	Clupeids	*Pomoxis*	Commercial
16	1	488	2	4	2	8	51	7	36
13	11	605	2	1	9	5	29	2	53
12	23	1,065	3	0.5	10	4	51	3	29
10	43	693	2	0.9	9	5	39	0.7	43
2	1	775	7	0.9	8	24	30	0.6	25

Sewage effluent from Arkansas cities also affects the river water quality. However, the Arkansas River today is much cleaner than in past years because of improvements in sewage treatment and better monitoring of municipal and industrial effluent. The direct releases of dioxin into Pool 3 (Pine Bluff) and tributaries near Little Rock (Bayou Meto) have created a major pollution problem. Commercial fishing on Bayou Meto has been banned since 1979 because of the release of this toxic compound from a nearby chemical manufacturing plant. Commercial poultry production is becoming a factor in water quality of tributary streams to the river.

As previously mentioned, the Arkansas River carries large amounts of sediment. A discharge of 9,828,182 metric tons at Lock and Dam 13 occurred in 1971. Considerable dredging is therefore required to maintain the commercial navigation channel. Pool 10 is the only pool where extensive dredging is not done; Dardanelle acts as a silt trap for the remainder of the navigation system. A total

Table 6. Water quality parameters from Arkansas River in Oklahoma. Values are averages for sample year October 1989–September 1990 (U.S. Geological Survey 1990).

Parameter	Ralston	Tulsa	Kerr
Dissolved oxygen (mg/L)	9.2	8.1	7.5
Total alkalinity (mg/L CaCO)	186	140	101
Total hardness	256	231	140
Dissolved chloride (mg/L)	226	322	95
Dissolved solids (mg/L)	710	858	339
Total phosphorus (mg/L)	0.16	0.14	0.04
Total nitrite/nitrate	0.6	0.6	0.34
Turbidity (NTU)	25	18.4	

Table 7. Water quality parameters from the Arkansas River in Arkansas. Values are medians for data collected from 50 monitoring stations monitored monthly from 1975 to 1985 (Peterson 1988).

Parameter	Lock & Dam 13	Lock & Dam 8	Lock & Dam 3
Dissolved oxygen (mg/L)	8.8	9.4	9.3
Total alkalinity (mg/L)	93	82	74
Total hardness	140	108	111
Dissolved chloride (mg/L)	110	81.5	85.5
Dissolved solids (mg/L)	359	336	324
Total phosphorus (mg/L)	0.10	0.09	0.12
Total nitrite/nitrate	0.28	0.37	0.33
Fecal coliform	110	40	80
Turbidity	1	25	20

of 2.5 million m^3 of sediment was dredged from the Arkansas River system in 1990, and 0.25 million m^3 was removed from the White River portion of the system. In 1991, 0.62 million m^3 of sediment was removed from the Arkansas, and 0.69 million from the White River portion. Dredged material disposal areas can create habitat diversity and provide important spawning nursery, and feeding grounds for forage and predator species of fish. When dredge spoils are deposited in or near access routes to these areas from the main channel or when the site itself is filled, the area is no longer usable to the fishery, which adds to the cumulative loss of critical habitat.

Development

For years navigation proponents have complained that occasional low water levels in the White River channel of the Arkansas River Navigation Project are negatively affecting use of the waterway. The U.S. Army Corps of Engineers therefore proposed construction of a new lock and dam at Montgomery Point (rkm 0.3). This would negate the need for extensive dredging now required along the 15-km channel. An innovative dam would act as a baffle and would allow for fish migration most of the year except during periods of low flow, when the dam would be raised from the river bottom to keep the channel at navigation depth. This project, estimated at $220 million in 1990, would destroy hundreds of hectares of bottomland hardwoods in an area of the Mississippi delta long revered for its remote and productive wetlands. There is also concern that migration of shovelnose sturgeon would be adversely affected. The project has recently been postponed because of cost and negative environmental effects.

Deepwell irrigation has put considerable pressure on aquifers in central and eastern Arkansas. Therefore, two water diversion projects are currently under construction to provide relief. In response to aquatic resource concerns the Arkansas Soil and Water Commission has been given authority to set a minimum stream flow for the Arkansas River. The Arkansas Game and Fish Commission's minimum flow determination and that of the Arkansas Soil and Water Commission are not in agreement.

Future hydroelectric plants are also possible on remaining locks and dams in Arkansas and Oklahoma as new sources of clean electric power become necessary. One pump-storage hydroelectric plant is now being studied on Pool 10 for producing electricity during peak power times.

Recommendations

1. Kansas should develop and implement an acquisition plan for the river similar to that of the Colorado Division of Wildlife. This plan provides control and the ability to manipulate present land practices and recommends management strategies to large landowners to sustain and increase fish and wildlife populations. Management strategies such as natural regeneration of native grasses and woody phreatophytes, removal of domestic livestock along riverbottoms, and removal of crops from or prohibiting farming in river bottom (channel) should be developed to sustain and increase fish and wildlife populations.
2. Resource agencies in Arkansas and Oklahoma should work with the U.S. Army Corps of Engineers to develop a master plan to benefit riverine aquatic resources. The plan should include recommendations for water level management and flow rates. Solutions and compromises that will protect and enhance the river's important fishery resources should be detailed.
3. The proposed Montgomery Point Lock and Dam project should be opposed because of significant adverse effect on bottomland timbered wetland habitat and possible adverse effect on migration of riverine fisheries.
4. Agencies should develop and implement a program to improve present methods of dredge–spoil disposal on the Arkansas River. The basis for this effort should be the ideas proposed by Buchanan (1976) and Inmon (1988) and should keep dredge–spoil away from the openings of backwater areas either behind dikes or tributaries. Agencies should work with the U.S. Army Corps of Engineers to locate areas that could be used for nursery pond sites to mitigate for loss of habitat due to dredge-spoil deposition.
5. A program should be developed and implemented, using notched dikes (such as on the Missouri River), to create aquatic habitat diversity and to retard the loss of habitat because of accretion and sedimentation.

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The Kansas River System and Its Biota

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Abstract. The Kansas River basin extends from the plains of northeastern Colorado 772 km eastward, draining 159,171 km^2 in northern Kansas, southern Nebraska, and northeastern Colorado. West to east, mean annual precipitation increases from less than 41 cm to greater than 90 cm, and average runoff increases from less than 0.25 cm to greater than 20.32 cm, but year-to-year departures from these averages are extreme. Mean daily discharge of the Kansas River near its mouth has been 200 m^3/s in water years 1917–91, with extremes of 13,764 m^3/s in 1951 and 4.5 m^3/s in 1956. About 90% of the area is utilized in farm and ranch enterprises, more than 50% being cultivated. Unregulated commercial dredging in the lower reach of the Kansas River mainstem resulted in severe riverbed degradation, bank erosion, and channel widening. Eighteen federal reservoirs and more than 13,000 smaller impoundments now control discharge from more than 80% of the drainage area, reducing fluctuation in flow and sediment load downstream. Dewatering of many western streams has resulted from conservation practices and ground and surface water irrigation pumpage. General water quality changes for the lower Kansas River basin include decreasing levels of suspended sediment and ammonia, and increasing concentrations of nitrate, phosphate, and dissolved oxygen. Water samples analyzed for major metals and trace elements on main tributaries and the mainstem lower Kansas River exceeded the chronic freshwater aquatic life criteria in 36% of samples. None of the 21 pesticides detected in the lower Kansas River basin exceeded acute freshwater aquatic life criteria, and occurrences of organophosphorus insecticides were limited. Atrazine and alachlor were the most frequently detected herbicides in the lower Kansas River basin. The Kansas River switches from an autotrophic to a heterotrophic system, depending on local and general

stream conditions. Downstream of wastewater treatment facilities, fecal coliform bacteria densities in the lower Kansas River basin often exceeded the secondary-contact recreational use criteria established by Kansas Department of Health and Environment. Phytoplankton and zooplankton abundance in Kansas River varies seasonally and with discharge from reservoirs. Recent plankton counts greatly exceed counts reported in years before impoundment. Benthic algae form extensive, thin mats where light penetrates to stable substrates under low-flow conditions. Benthic invertebrates of at least 4 phyla, 43 families, and 60 genera now occur in the lower mainstem. Ninety-nine species of fish inhabit the basin, of which at least 24 probably are introduced; the distribution and abundance of most species has changed markedly in this century. Major stresses in the basin include dewatering of western tributaries, riverbed degradation in the lower reach, and adverse water quality effects by agricultural, industrial, and municipal practices. Restoration needs include expanding existing stream monitoring programs, increasing streamflow to dewatered streams, establishing riparian zones, and enhancing enforcement.

The Kansas River system begins at an elevation of about 1,200 m in eastern Colorado and flows easterly about 772 km, entering the Missouri River at an elevation of 225 m in Kansas City, Kansas (Fig. 1). Total drainage area covers 159,177 km^2 (11.6% of Missouri River watershed) in northeastern Colorado, southern Nebraska, and the northern half of Kansas (Metcalf 1966). The mainstem Kansas River is formed by the confluence of the Republican and Smoky Hill rivers near Junction City, Kansas, at an elevation of 311 m (Fig. 2). Other major tributaries include the Solomon, Blue, and Saline, one of the saltiest rivers in the continental United States (Parker 1911).

Climate varies greatly across the drainage, from western semiarid high plains with less than 41 cm average annual rainfall and less than 0.25 cm runoff to the humid eastern extreme of the basin, which receives greater than 90 cm of precipitation resulting in greater than 20.32 cm of annual runoff (Colby et al. 1956; Geiger et al. 1991). During normal years about two-thirds of the total annual precipitation falls during April through September (Colby et al. 1956). Mean daily discharge of the Kansas River near its mouth has been 200 m^3/s in water years 1917–91, with extremes of 13,764 m^3/s in 1951 and 4.5 m^3/s in 1956 (Geiger et al. 1991). The mean annual temperature varies from 10° to 13° C at various gaging stations in the basin. At Good-

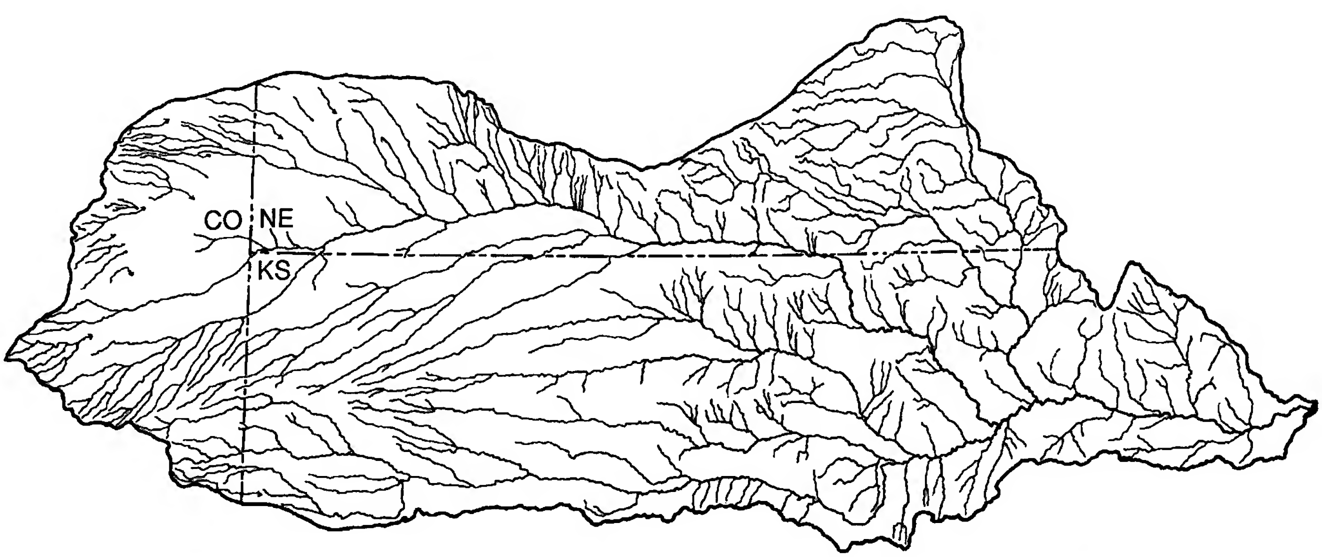

Fig. 1. Drainage pattern of the Kansas River basin. CO = Colorado, KS = Kansas, NE = Nebraska.

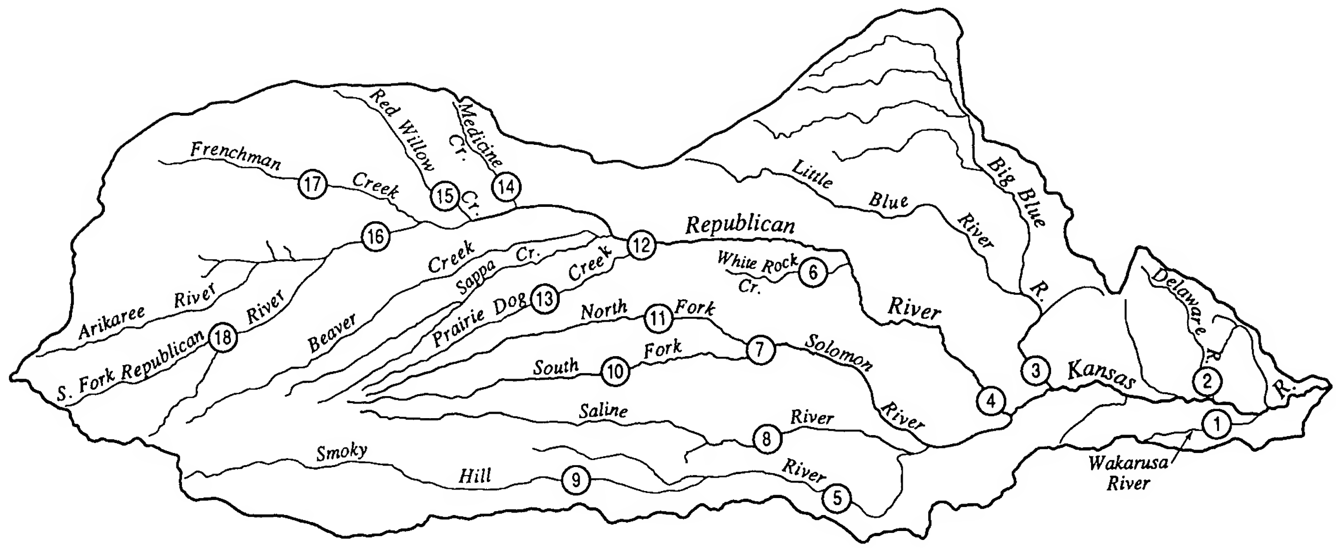

Fig. 2. Principal streams and towns mentioned in this report on the Kansas River basin.

land, Kansas, in the west, the mean January temperature is − 3.5° C, with normal daily extremes of −11° C and +4° C; the mean July temperature at Goodland is 24° C, the normal daily extremes 16° C and 33° C. At Topeka, in the east, mean January temperature is −1.7° C, with normal daily extremes of −7° C and +4° C; the mean July temperature at Topeka is 26° C, the normal daily extremes 20° C and 33° C. Air temperatures exceeding 39° C have been recorded at many stations in June, July, August, and September. The average frost-free period is 157 days at Goodland, 200 days at Topeka (Robb 1959). Water surface temperatures in summer commonly reach 30° C in streams throughout the basin, and occasionally exceed 32° C (e.g., Minckley 1959).

Physiography

The Kansas River system flows west to east through five physiographic provinces: High Plains, Smoky Hills, Flint Hills, Glaciated Region, and Osage Cuestas (Fig. 3; U.S. Army Corps of Engineers 1988). The High Plains occupy about one-third of the drainage from west-central Kansas and central Nebraska to the western extreme of the basin. Surficial materials form a locally shifting mantle of silt composed of Pleistocene silt and aeolian deposits (Simons, Li & Associates 1984). Erosion along stream channels in this province is low, less than 70 metric tons/km^2/year (Osterkamp et al. 1982). The Smoky Hills Province has steeply dissected plateaus (U.S. Army Corps of Engineers 1988) with irregular hills. Surficial material is predominately moderate to coarse-textured, probably derived from the sandstone underlying much of the area. Sediment yield from this area is moderate, 70–211 metric tons/km^2/year (Osterkamp et al. 1982). Stream gradients are moderate in the High Plains and Smoky Hills provinces: about 0.72 m/km for the lower 656 km of the Smoky Hill River, from Elkader downstream, and about 0.94 m/km for the lower 622 km of the Republican River, from Benkelman downstream (Fig. 2). The Flint Hills orient north–south from 36 km south of Nebraska to the Oklahoma border. This 64-km-wide province is characterized by rolling hills. Rangeland composed of tall grass prairie predominates owing to impediments to cultivation, namely rocky soils and sharp relief of escarpments. Tributaries to the Blue and Kansas rivers in this area are relatively clear owing to lack of cultivation, and they have high gradients (8 to 16 m/km; Minckley 1959; Metcalf 1966). A series of prominent cuesta scarps and dip slopes developed on resistant cherty limestone of Permian age characterizes the region (Simons, Li & Associates 1984). Part of this province exhibits moderate sediment yield, 70–211 metric tons/km^2/year. However, in areas of fine-grained evaporite outcroppings relatively large sediment yields (211–702 metric tons/km^2/year) occur (Osterkamp et al. 1982). The Glaciated Re-

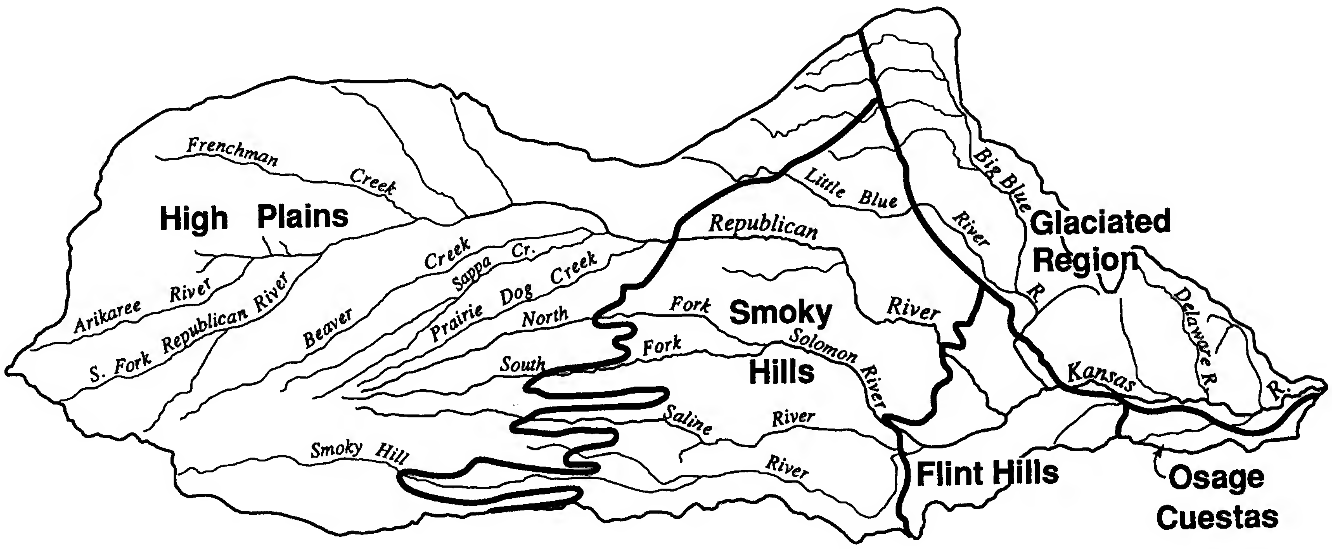

Fig. 3. Physiographic provinces of Kansas River basin.

gion is a gently undulating dissected plain (U.S. Army Corps of Engineers 1988) that was influenced by ice from two major glaciations, the Nebraskan and the Kansan (Frye and Leonard 1952). Nebraskan glacial till has been eroded or overlain by deposits so that Kansan glacial till is more prevalent (Metcalf 1966). This area produces large sediment yields of 211–702 metric tons/km^2/year (Osterkamp et al. 1982). Gradients of most streams in the Glaciated Region are low (e.g., 0.5 m/km in Black Vermillion River, tributary to Blue River) compared to streams draining unglaciated uplands south of Kansas River (e.g., 3.0 m/km in the Wakarusa River; Minckley 1959; Deacon and Metcalf 1961). Kansas River system flood-plain soils are derived from alluvium consisting of water-laid deposits of silt, clay, sand, and gravel (U.S. Army Corps of Engineers 1988). The gradient of the mainstem Kansas River varies from about 0.5 to 1.2 m/km (Simons, Li and Associates 1984).

Land Use

Land use for the basin within the State of Kansas is predominately cropland (53–56%) and pasture (37–41%), based on U.S. Soil Conservation Service data for 1982 and 1987 and Colby et al. (1956). Forested areas accounted for less than 2% by cover type, and much of this exists as riparian habitat, especially in central and western portions of the basin. Urban areas (Kansas City metropolitan area) are concentrated in the lower 35 km of the Kansas River mainstem. Lawrence, at river kilometer (rkm) 84, and Topeka, at rkm 140, are the only other two cities with populations greater than 50,000 in the drainage (U.S. Census Bureau 1981).

Channel Migration

Maps generated for periods between 1857 and 1976 for the eastern half of the drainage within Kansas (Dort et al. 1981) showed stream reaches in the western part of the study area migrated more than those in the east. In addition, only 12% of the Kansas River mainstem shifted laterally greater than channel width from 1936 to 1976. Less than 10% of the mainstem has actively migrated since 1951, indicating mobility is declining (U.S. Army Corps of Engineers 1988).

Physical Modifications

One of the earliest recorded physical modifications within the system began during the 1860's with the construction of Rocky Ford Dam, a wooden gristmill dam on the Big Blue River. Located 13.7 km upstream of the confluence of the Big Blue and Kansas rivers, this 178.6-m-long structure was reconstructed of concrete twice

(C. Bever, Kansas Department of Wildlife and Parks, personal communication).

The Bowersock Dam was built on the Kansas River in 1872 at Lawrence, Kansas, at rkm 83.4. Repairs and enhancements in 1903 and 1916 extended the dam from 182.9 to 239.9 m in length (Simons, Li & Associates 1984).

Two weirs, one constructed in 1964 at rkm 24 (Simons, Li & Associates 1984) and the other constructed in 1986 at rkm 140 (U.S. Army Corps of Engineers 1990) are associated with water intakes. In addition, one diversion jetty in conjunction with a water intake is present at rkm 53 and two jetties at rkm 140 (U.S. Army Corps of Engineers 1990).

Numerous bank stabilization structures are present on the Kansas River mainstem. Most of this activity occurred during the 1950's as a result of the 1951 flood. About 16% (84.8 of 548.5 km of riverbank) of the mainstem has been modified (Simons, Li & Associates 1984).

Channelization has occurred on many Kansas River tributary streams. Unfortunately, records of permitted activities are not readily retrievable, and severity of illegal channel work is unknown (R. LaForce, Kansas State Board of Agriculture, Division of Water Resources, personal communication).

Commercial dredging has occurred on the Kansas River since the 1900's. About 15 active operations dredge sand and gravel from the river annually. Most of the dredging activity (75–80% of material removed) occurs in the lower 35 km. During 1984–87, 1.35×10^7 metric tons were extracted from the river; 1.06×10^7 metric tons (78%) came from rkm 0–35. Intense dredging in the lower 35 km of the Kansas River removed sand and gravel at an annual rate of 2.16×10^6 metric tons during a 5-year study (1979–83). Average annual material replacement was about 1.51×10^6 metric tons, based on 1935–74 flow duration curves at the DeSoto, Kansas (rkm 50), gauging station. Dredging in the lower reach of the Kansas River has resulted in severe riverbed degradation (2.4–4.6 m), bank erosion, and channel widening (about 45.7 m; U.S. Army Corps of Engineers 1990).

Because of the aforementioned effects on the integrity of the Kansas River, the U.S. Army Corps of Engineers developed permitting guidelines in 1990 for dredging. Limits were established for selected reaches, and a 680,250 metric ton annual extraction limit was placed on any 24.1-km reach from rkm 34.1 to 274.2. The maximum annual extraction per dredge is limited to 272,100 metric tons of material. The maximum length of any reach of river authorized for dredging under a single permit is 2.4 km. A minimum distance of 609.6 m is required between permitted reaches of dredging activities. Only one dredge can operate within a single permitted reach (U.S. Army Corps of Engineers 1990).

One of the greatest alterations to the river system has been the construction of reservoirs on every major tributary (Fig. 4). Reservoir construction began during the 1940's, but flourished during the 1950's (Table 1), probably in response to the 1951 flood. Eighteen large federal reservoirs and over 13,000 smaller impoundments (Mundorff and Scott 1964) control over 80% of the Kansas River drainage (Simons, Li & Associates 1984). Reservoirs have modified the Kansas River system flow regime by attenuating flows (Fig. 5). Reduction of flood flows has decreased lateral migration (Simons, Li & Associates 1984). Reservoirs within the Kansas River drainage trap 95–98% of all suspended sediment and 100% of sand-sized particles (Simons, Li & Associates 1984), which has decreased sediment flow (Cross and Moss 1987). Annual average sediment yield in the lower Kansas River declined from 23.48×10^9 kg for 1958–61 (before reservoir system completion) to 7.71×10^9 kg for 1978–80 (after reservoir system completion), even though water yields were similar (within 6%) between periods (Cross and Moss 1987). Clear water releases resulted in substantial degradation, up to 3 m within about 12 years of operation, immediately below reservoir dams. However, degradation of stream beds decreased rapidly to levels of 0.6 m at distances of 13 km downstream of dams (Simons, Li & Associates 1984).

Hydrology of Western Drainage Area

Bureau of Reclamation reservoirs located in the western portion of the drainage were built primarily for irrigation. However, declining water levels have negatively affected irrigation and recreation at several reservoirs. For example, flows in the Smoky Hill River upstream of Cedar Bluff Reservoir in western Kansas show decreased discharges after 1975 (Fig. 6). Reduced flows have resulted in declining water volume within Cedar

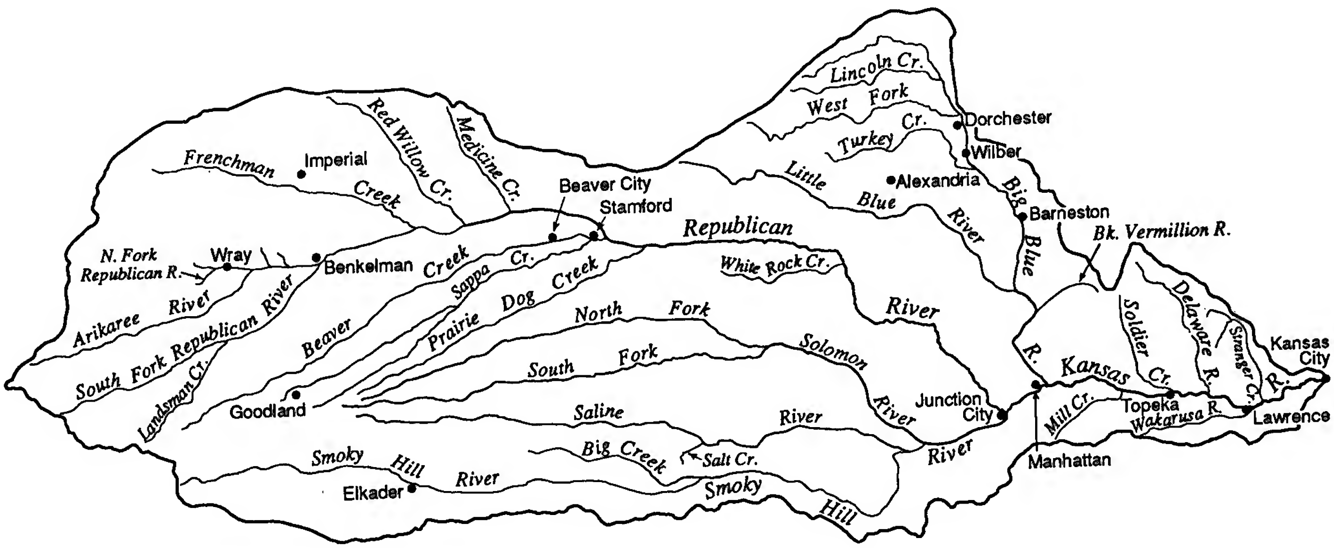

Fig. 4. Major reservoirs in the Kansas River basin. 1, Clinton; 2, Perry; 3, Tuttle Creek; 4, Milford; 5, Kanopolis; 6, Lovewell; 7, Glen Elder; 8, Wilson; 9, Cedar Bluff; 10, Webster; 11, Kirwin; 12, Harlan County; 13, Norton; 14, Harry Strunk; 15, Hugh Butler; 16, Swanson; 17, Enders; and 18, Bonny.

Table 1. Reservoirs in the Kansas River basin (Simons, Li and Associates 1984; B. Peck, U.S. Bureau of Reclamation, personal communication; B. Pearce, U.S. Army Corps of Engineers, personal communication).

Reservoir	Drainage area (km^2)	Volume at normal pool $10^6 m^3$	Surface area (ha)	Date of operation
Clinton	951	136	2,833	1977
Perry	2,894	277	4,707	1969
Tuttle Creek	24,871	524	6,394	1962
Milford	9,832	504	6,483	1967
Kanopolis	20,363	65	1,437	1948
Lovewell	933	51	1,208	1957
Wilson	4,966	306	3,642	1964
Glen Elder	13,161	298	5,100	1968
Kirwin	3,653	123	2,053	1955
Webster	3,044	95	1,524	1956
Cedar Bluff	14,327	228	2,780	1950
Norton	1,788	44	883	1964
Harlan County	5,376	389	5,367	1952
Harry Strunk	2,280	44	745	1949
Hugh Butler	1,891	47	659	1961
Swanson	22,332	138	1,992	1953
Enders	2,461	54	691	1950
Bonny	4,715	51	826	1950

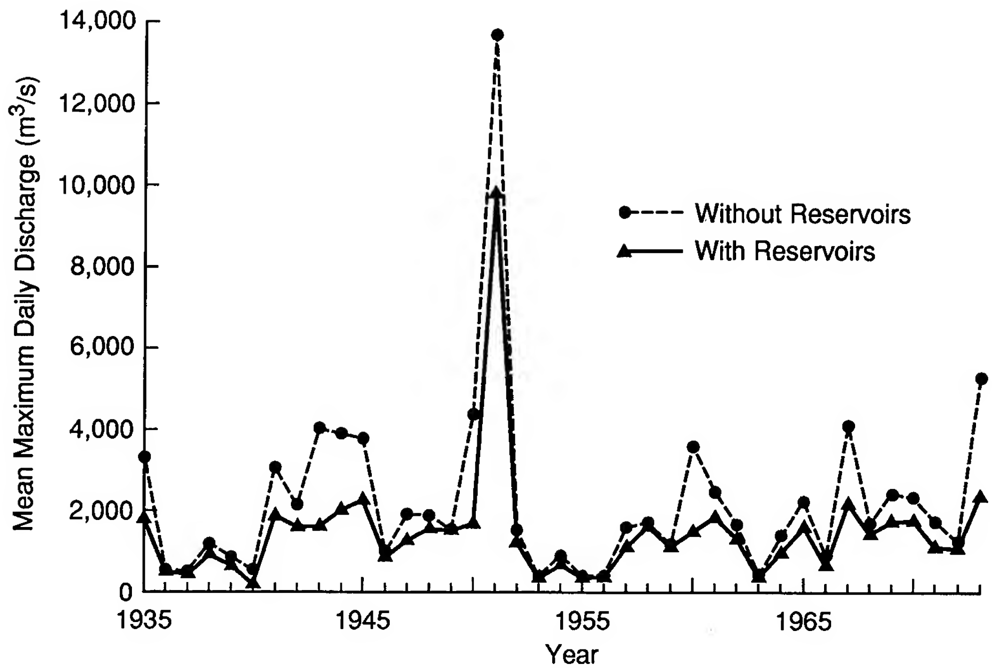

Fig. 5. Model of lower Kansas River flows with and without reservoir system influence (Simons, Li & Associates 1984).

Bluff (Fig. 7) and reduced outflows (Fig. 8). This general pattern is prevalent across this region, as South Fork Solomon River-Webster Reservoir, North Fork Solomon River-Kirwin Reservoir, Prairie Dog Creek-Norton Reservoir, Frenchman Creek-Enders Reservoir, and Republican River-Swanson Reservoir have experienced long-term water shortages.

Change in precipitation was discounted as a factor in streamflow and reservoir water level depletions in the Solomon basin (Jordan 1982; U.S. Bureau of Reclamation 1984b), Beaver Creek, and upper Smoky Hill River basins (Jordan 1982); however, cyclical variation in the precipitation regime within the Republican River basin was listed as a factor (U.S. Bureau of Reclamation 1985).

Surface water runoff studies conducted in western Kansas documented decreased runoff over time, with similar average annual precipitation within the four Kansas River basin stream drainages examined. Average yearly runoff within the North Fork Solomon River basin upstream from Kirwin Reservoir declined from 49.32×10^6 m^3 during 1953–69 (annual precipitation averaged 53.34 cm) to 23.43×10^6 m^3 during 1970–78 (annual precipitation averaged 53.85 cm). Average yearly runoff in the Smoky Hill River basin upstream from Elkader, Kansas, declined from 29.59 $\times 10^6$ m^3 during 1940–68 (annual precipitation averaged 45.47 cm) to 6.90×10^6 m^3 during 1969–78 (annual precipitation averaged 46.23 cm). Decreases of 50% or more in the amount of runoff resulting from normal precipitation occurred within South Fork Solomon and Beaver Creek basins from 1948–66 to 1967–75 (Jordan 1982).

Runoff decreases are due primarily to conservation practices, especially ponds and terraces (Jordan 1982; U.S. Bureau of Reclamation 1984b, 1985). By 1978, upstream of Kirwin Reservoir in the North Fork Solomon drainage, there were 2,030 ponds and 116,554 terraced ha, which had depleted a total of 8.01×10^8 m^3 from runoff. Likewise, upstream of Webster Reservoir in the South Fork Solomon drainage, there were 820 ponds and 77,702 terraced ha, which had depleted runoff a total of 7.40×10^8 m^3. By 1978, in watersheds of the North and South forks of the Solomon River below Kirwin and Webster reservoirs and above Glen Elder Reservoir there were 3,950 and 2,100 ponds constructed, respectively. In addition, there were 65,966 terraced ha on the North Fork and 44,921 terraced ha on the South Fork by 1978. By 1978, conservation practices had reduced runoff into the North Fork Solomon by 5.65×10^7 m^3, and runoff into the South Fork Solomon by

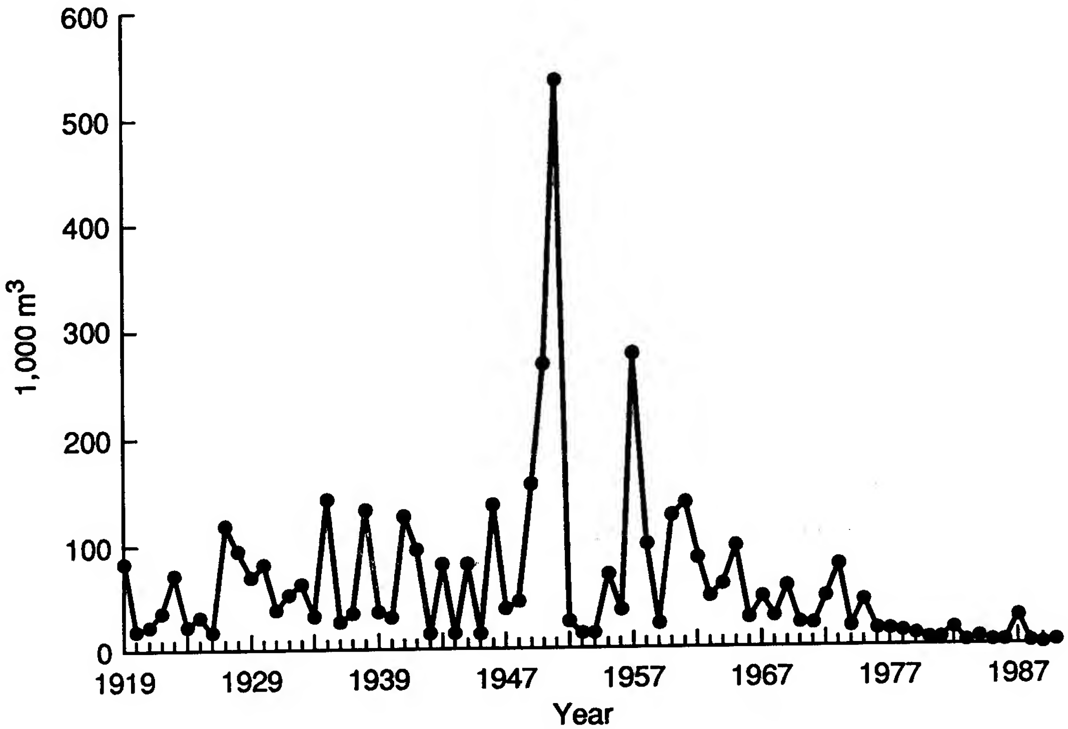

Fig. 6. Total annual flow of Smoky Hill River upstream of Cedar Bluff Reservoir.

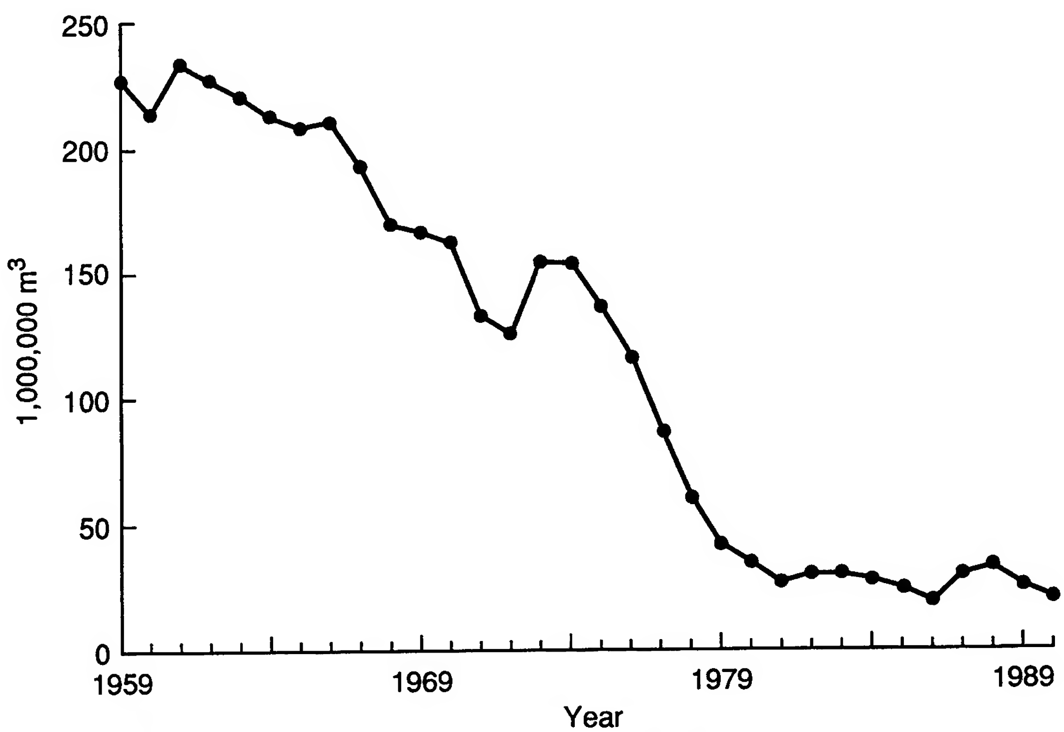

Fig. 7. Average annual end of month contents for Cedar Bluff Reservoir.

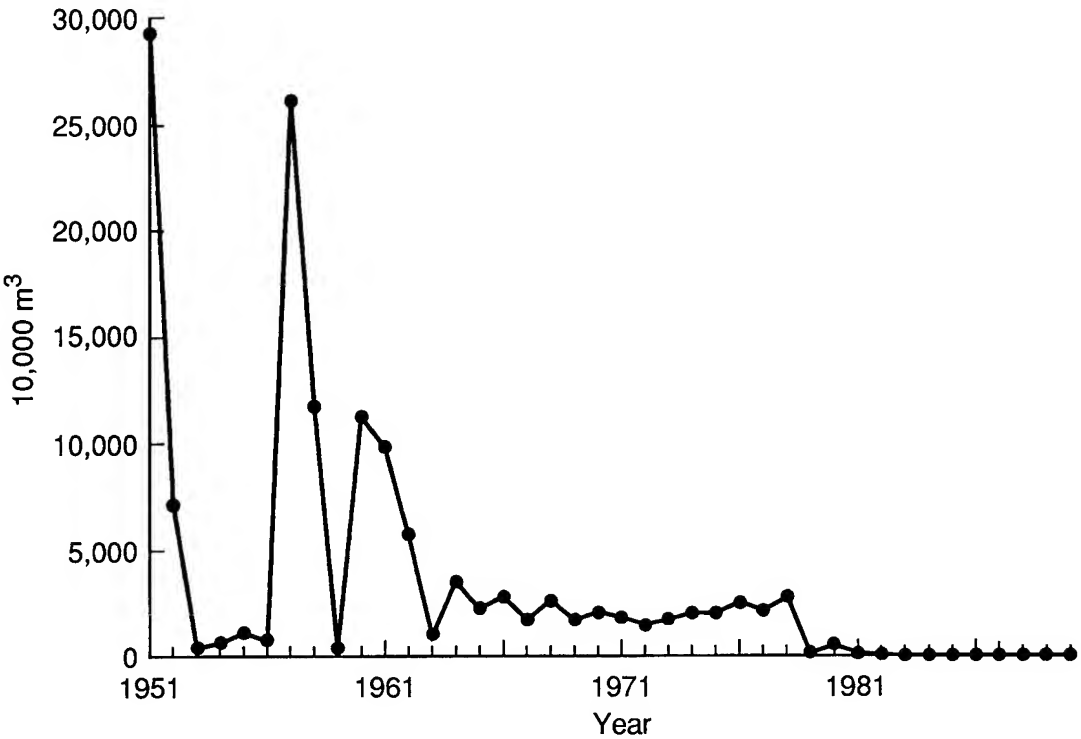

Fig. 8. Total annual flow of Smoky Hill River downstream of Cedar Bluff Reservoir.

4.12×10^7 m^3. In 1978, the watershed below Glen Elder Reservoir on the mainstem Solomon River had an estimated 27,115 ha of terraces and 2,420 ponds. Total water depletion for this reach because of conservation practices between 1930 and 1978 was 6.35×10^8 m^3 (U.S. Bureau of Reclamation 1984b). A total depletion of 1.43×10^{10} m^3 for the Republican River basin because of conservation practices has been estimated for 1949–78 (Bureau of Reclamation 1985).

As of 1980 a combined (irrigation and conservation practices) estimate of depleted inflow to Cedar Bluff Reservoir through the Smoky Hill River was 61%. Conservation practices were present on 477,586 of the 1,432,314 ha of the Cedar Bluff drainage by 1980 (U.S. Bureau of Reclamation 1984a).

Besides conservation practices, groundwater pumpage is the other major factor decreasing streamflows and reservoir water levels in the western portion of the Kansas River basin (Jordan 1982; U.S. Bureau of Reclamation 1984a, 1984b, 1985). By 1978, about 14,649 wells were present in the Republican basin. These wells pumped an estimated 2.63×10^9 m^3 of water in 1978 and irrigated 620,446 ha. Several streams within the Republican basin have experienced declines in base flow (Table 2) as a result of well development (U.S. Bureau of Reclamation 1985).

Jordan (1982) found that 25–33% of the decrease in streamflow represents a reduction in base flow and was correlated with an increase in groundwater pumpage for all four Kansas River system streams surveyed (Beaver Creek, upper Smoky Hill River, North and South Fork Solomon rivers upstream of Kirwin and Webster reservoirs). Annual depletion above Kirwin Reservoir because of pumping was estimated at 1.76×10^7 m^3 and above Webster Reservoir 2.17×10^7 m^3. Pumpage from wells has lowered water levels in Sheridan County, Kansas, by as much as 12.19 m. Base flows in the North Fork Solomon River have been declining since 1962. Average annual base flow for the North Fork Solomon declined from 8.5×10^6 m^3 for 1955–62 to 7.03×10^6 m^3 after 1962. Base flow in the South Fork Solomon River above Webster Reservoir decreased from an average of 2.19×10^7 m^3/year before 1966 to an average of 7.27×10^6 m^3/year since 1966 (U.S. Bureau of Reclamation 1984b).

Consumption of ground water has exceeded safe yields in the North Fork Solomon basin since

Table 2. Declines in base flow of Republican River tributaries (U.S. Bureau of Reclamation 1985)

Stream	Year decline began	Percent decline (%)
Landsman Creek (Hale, Colorado)	1962	42
Arikaree River (Haigler, Nebraska)	1953	50
Buffalo Creek (Haigler, Nebraska)	1959	15
Frenchman Creek (Imperial, Nebraska)	1968	28
Frenchman Creek (Palisade-Culbertson, Nebraska)	1968	29
Beaver Creek (Cedar Bluffs, Kansas)	1968	98
Sappa Creek (Beaver City, Nebraska)	1955	44
Sappa Creek (Stamford, Nebraska)	1968	85
Prairie Dog Creek (above Norton Reservoir, Kansas)	1970	66

1965 and in the South Fork Solomon basin since 1964. Under current levels, base flows of zero were to be reached by 1989 in the North Fork Solomon and 1993 in the South Fork Solomon (U.S. Bureau of Reclamation 1984b).

Kansas Division of Water Resources (KDWR) began limiting ground and surface water appropriations in 1983 in the Kansas River basin. Generally, applications for permits to appropriate water for beneficial use, except for domestic use, temporary permits, and short-term permits after the effective date of the respective administrative policy, are denied unless determinations indicate water is available to appropriate. Streams, restriction types (surface or ground water), and years in which administrative policies became effective are as follows: Solomon River basin, surface water cannot be diverted between 15 June and 15 September, 1983; South Fork Solomon River upstream of Webster Reservoir, ground water, 1983; North Fork Solomon River and Bow Creek upstream from Kirwin Reservoir, ground water, 1983; South Fork Solomon River and tributaries above Glen Elder Reservoir, surface and ground water, 1984; Little Beaver Creek, Beaver Creek, and tributaries, surface and ground water, 1984; Big Creek and tributaries outside of Northwest Kansas Groundwater Management District 4, surface and ground water, 1984; Smoky Hill River and tributaries between its confluence with Big Creek and its confluence with the Solomon River, surface and ground water, 1989; and the lower Republican River basin, surface and ground water, 1990 (B. Turney, KDWR, personal communication).

No surface water moratorium exists in the system in Nebraska. The upper Republican basin (Perkins, Chase, and Dundy counties) has ground water allocation limits in effect. As of 1993, an area within the Little Blue Natural Resources District (Adams, Clay, Nuckolls, Fillmore, and Thayer counties) will begin allocations of ground water (S. France, Nebraska Department of Water Resources, personal communication).

No new appropriations have been granted as of 1990 within the Northern High Plains Groundwater District, which encompasses the Kansas River drainage in Colorado. An exception is made for wells that flow less than 0.45 m^3/min, and these appropriations are readily granted. Surface water appropriations are not viable in most cases because senior water right holders use available water (B. Saunders, Northern High Plains Groundwater Management District, personal communication).

Minimum desirable streamflows (MDS) have been established for some reaches within the Kansas River basin in Kansas and Colorado in an effort to preserve stream habitat. Minimum desirable streamflows were established in 1987 for the Saline, Smoky Hill, Big Blue, Little Blue, Republican, and Delaware rivers and in 1989 for the Solomon River and Chapman Creek (near Manhattan) in Kansas. The Arikaree and North Fork Republican rivers and Chief Creek (a North Fork Republican River tributary west of Wray) have MDS in Colorado (J. Skinner, Colorado Division of Wildlife, personal communication). To date, Nebraska streams within the Kansas River system have no MDS protection (D. Jensen, Nebraska Department of Environmental Control, personal communication). Minimum desirable streamflows provide for limited flows at a point or within a reach, but in most cases enhancement is local (C. Mammoliti, Kansas Department of Wildlife and Parks, personal communication; J. Skinner, Colorado Division of Wildlife, personal communication).

Water Quality

The water quality of the Kansas River probably declined between the late 1800's and mid 1900's in response to increases in human population, agricultural activities, and the slow but steady growth of industry in the basin. Unfortunately, we do not have reliable long-term records of water quality for the major rivers of North America (Wolman 1971). Although published surface water quality records for the State of Kansas can be found as far back as 1889, it was not until the early 1960's that such data became abundant and regular enough to be meaningful in interpreting existing or changing conditions of most water quality parameters (Hulen and Angino 1976). Since 1962, water quality records and data have become increasingly available through the monitoring and assessment efforts of several state and federal agencies and organizations (i.e., U.S. Geological Survey, U.S. Environmental Protection Agency, Kansas Department of Health and Environment). In addition, numerous water quality studies have been conducted on various smaller tributaries of the Kansas River by university and other state agency personnel. For the most part, studies of the water quality of streams and rivers of the Kansas River basin are somewhat limited in scope, and few studies have been conducted on the Kansas mainstem or its major tributaries (i.e., Saline, Solomon, Smoky Hill, and Republican rivers). The preceding statements are not meant to suggest that water quality data are lacking for the Kansas River basin. However, much of these data cannot be used in a rigorous and robust analysis of the water quality associated with historic and current conditions in the Kansas River and its major tributaries. In this regard, we have focused most of our discussion on findings summarized in the study of the lower Kansas River basin conducted by the U.S. Geological Survey (Jordan and Stamer 1991) as part of its testing and refinement of concepts for a National Water-Quality Assessment (NAWQA) Program. Data used by Jordan and Stamer in their study represent the most complete compilation of water quality information available on the lower Kansas River to date. Unless otherwise noted, results and discussion will concern mainstem condition on the Big and Little Blue rivers and the Kansas River (from the confluence of the Smoky Hill and Republican rivers to its confluence with the Missouri River; Fig. 2). Only selected parameters are discussed in the following water quality groupings.

Suspended Sediment

Concentrations of suspended sediment (mostly silt and clay) are large enough to give the water from the lower Kansas River basin a turbid appearance in many water samples, such that the median concentration of suspended sediment is 280 mg/L for the general period between 1963 and 1986, depending on sampling site (Jordan and Stamer 1991). The largest current suspended sediment yields are from the Blue River drainage because of the erodible glacial till, topography, high precipitation (Jordan and Stamer 1991), and large amount of cultivated land. The long-term trend for suspended sediment (as with other parameters) was tested using the seasonal Kendall Test (Hirsch et al. 1982). Time trends in flow-adjusted concentrations of suspended sediments indicated a downward trend at six of eight sampling sites, but only three site analyses were significant at the 0.10 probability level (Table 3).

Construction of major federal reservoirs throughout the Kansas River basin, plus thousands of smaller impoundments constructed by numerous federal, state, and local entities, has reduced the suspended sediment values in the Kansas River and major tributaries (Cross and Moss 1987). The discussions provided by Jordan and Stamer (1991) suggest that improved land management (i.e., terraces and grassed waterways) is contributing to the downward trend in suspended sediment in the lower Kansas River and the Big Blue River. While, overall, the Kansas River is becoming less turbid because of reduced suspended sediments, the changes in bed load and streambed condition are unclear. Regulated flows as a result of impoundments, along with other land-based and river activities (i.e., dredging of sand and gravel, land use) within the basin, seemingly have imposed temporal and spatial changes in the flow regime and physical composition and nature of the river bed (Burns and McDonnell 1982; Cross et al. 1982). In total, these physical changes may be imposing cumulative effects on the ecology of the river in both a local (e.g., Cross et al. 1982) and basinwide sense. While many facets of the effects of reservoirs on stream ecosystems are understood, changes in the hydrology of rivers are as important as water quality changes that follow impoundment of rivers. Unfortunately, while direct evidence of bed load charac-

Table 3. Trend-test results for various water quality parameters from selected stations within the lower Kansas River basin.[a] Only results significant at 0.1 probability level are shown, and probability values shown as 0 are less than 0.005. Only the results of seasonal Kendall tests for time trend on flow-adjusted concentration data are presented. Table modified from Jordan and Stamer (1991).

Parameter	Locality	Inclusive years	Number of years	Probability level	Mean rate of change(%/yr)
Suspended sediment	Little Blue River (Barnes, Kansas)	1976–86	11	0.02	-8.1
Suspended sediment	Kansas River (Wamego, Kansas)	1957–85	29	0.00	-3.8
Suspended sediment	Kansas River (DeSoto, Kansas)	1975–86	12	0.05	-9.0
Ammonia	Big Blue River (Seward, Nebraska)	1973–86	14	0.02	-11.0
Ammonia	Big Blue River (Barneston, Nebraska)	1973–86	14	0.01	-11.0
Ammonia	Kansas River (Topeka, Kansas)	1967–81	15	0.06	-4.5
Nitrate	Big Blue River (Seward, Nebraska)	1970–86	17	0.04	+5.0
Nitrate	Lincoln Creek (Seward, Nebraska)	1970–86	17	0.01	+6.0
Nitrate	W. Fork Big Blue River (Dorchester, Nebraska)	1970–86	17	0.02	+2.1
Nitrate	Big Blue River (Crete, Nebraska)	1970–83	14	0.07	+3.2
Nitrate	Big Blue River (Barneston, Nebraska)	1968–86	19	0.05	+1.2
Total phosphorus	Big Blue River (Barneston, Nebraska)	1973–86	14	0.00	-9.3
Total phosphorus	Turkey Creek (Wilbur, Nebraska)	1973–86	14	0.10	-1.7
Total phosphorus	Big Blue River (Manhattan, Kansas)	1971–86	16	0.10	+2.6
Total phosphorus	Soldier Creek (Delia, Kansas)	1971–86	16	0.03	+7.4
Total phosphorus	Kansas River (Lecompton, Kansas)	1971–86	16	0.02	+6.1
Dissolved oxygen	Little Blue River (Alexandria, Nebraska)	1968–80	13	0.05	+1.2
Dissolved oxygen	Lincoln Creek (Seward, Nebraska)	1970–86	17	0.04	+1.0
Dissolved oxygen	Kansas River (DeSoto, Kansas)	1970–86	17	0.06	+9.8
Dissolved oxygen	Little Blue River (Hollenberg, Kansas)	1970–86	17	0.09	+0.7
Total copper	Little Blue River (Hollenberg, Kansas)	1974–86	13	0.01	+8.9
Total zinc	Kansas River (DeSoto, Kansas)	1974–86	13	0.05	-7.9
Fecal coliform	Kansas River (Wamego, Kansas)	1971–86	16	0.01	-15.0
Fecal coliform	Kansas River (DeSoto, Kansas)	1967–81	15	0.02	-8.4
Fecal streptococci	Kansas River (Topeka, Kansas)	1967–81	15	0.05	+8.9

Table 3. *Continued.*

Parameter	Locality	Inclusive years	Number of years	Probability level	Mean rate of change(%/yr)
Fecal streptococci	Kansas River (Lecompton, Kansas)	1971–86	16	0.04	+16.0
Fecal streptococci	Kansas River (DeSoto, Kansas)	1976–86	20	0.01	−10.0

[a] Time trend data not available for pesticides.

teristics and hydrological dynamics before the early 1900's is lacking, many changes can be assumed to have occurred.

Nutrients

Median station concentrations of total nitrate as nitrogen ranged from 0.09 to 2.30 mg/L, while dissolved orthophoshate as phosphorus varied from 0.02 to 0.30 mg/L (Jordan and Stamer 1991). Jordan and Stamer indicated that no temporal variations in nitrate were detected at stations located in cropland drainages, but nitrate and phosphorus species were typically greater in the Big Blue River basin than in the upper Kansas River basin (stations above the Blue River confluence with the Kansas River). Only ammonia nitrogen exceeded freshwater aquatic life criteria values established by U.S. Environmental Protection Agency (EPA), and these occurred in only 1–7% of the samples (1978–86). These findings indicate that principal point-source discharges of wastewater are not significant contributions of ammonia or that biochemical uptake and transformation is rapid. Few significant time trends were evident for ammonia, but most stations displayed downward trends (Table 3). These downward trends were attributed to improved farming practices and wastewater treatment (Jordan and Stamer 1991). Nitrate accounted for 50% of the total nitrogen measured in lower Kansas River waters. In general, trend tests for nitrate were inconclusive for most stations in the lower Kansas River, but a few station results revealed an upward trend, especially in basin areas dominated by cultivated cropping practices (Table 3).

In an early time-trend study of nitrate and orthophosphorus in Kansas streams, Hulen and Angino (1976) found that mean annual phosphate concentrations were increasing with time (1968–74) in the lower portions of the Smoky Hill and Republican rivers in Kansas. These authors noted that mean annual nitrate concentrations in many Kansas streams, including the Smoky Hill and Republican rivers, had increased in the period 1962 through 1974, but data from the one sample site near Kansas City revealed a downward trend in nitrate values. While no nitrate time-trends were identified for station data for the Solomon (three stations) and Saline (three stations) rivers by these authors, visual examination of their plotted values revealed increased concentrations for five of six stations did occur from 1968 through 1974.

Dissolved Oxygen and Biochemical Oxygen Demand

Jordan and Stamer (1991) concluded that dissolved oxygen (DO) and 5-day biological oxygen demand (BOD) data indicated that oxygen stress may not be a problem in the basin, but they noted that samples were made during daylight periods only. Therefore, their measurements are not representative of diel changes. This certainly lessens their usefulness as indicators of ecological stream health. Four of 15 stations tested for DO trends had significant (and positive) trends, and all stations displayed upward trends in DO. These authors suggested that upward trends in DO may be related to improved wastewater treatment, although most stations were located far from any large municipal wastewater treatment facility. In addition, Jordan and Stamer (1991) noted that daytime DO values in these streams were somewhat supersaturated, indicating a positive net photosynthetic DO production. About half of the river sites examined by Howick and Huggins (1987) during late summer sampling were found to have supersaturated DO values associated with the late evening sampling periods. Supersaturated conditions for DO were not observed at sites on the Kansas River but were found at sites on the Saline, Smoky Hill, and Solomon rivers. Diurnal changes in DO values were noted at nearly all

sites, but values never dropped below 5 mg/L for any Kansas River basin sites (Howick and Huggins 1987). However, care should be taken when interpreting these data, as they represent only a single sampling event. Marzolf (1979) stated that plankton populations in reservoir release water contributed little to planktonic chlorophyll in the Kansas River, but the river itself can be extremely productive because of both planktonic and benthic algal production. Decreases in suspended sediment and increases in stable flow conditions, partly owing to the large reservoirs situated throughout the basin, may be among those factors contributing to an increase in DO values as a possible result of increased algal production in the river.

Heavy Metals and Trace Elements

Jordan and Stamer (1991) concluded that 10 elements had higher concentrations than would be expected when compared with data from soils and surficial materials in the entire conterminous United States. In summary, of all water samples analyzed for major metals and trace elements in the main tributaries and Kansas River composing the lower drainage, the chronic freshwater aquatic life criteria were exceeded by 36% of the samples (>1,000 samples; Jordan and Stamer 1991). Total recoverable iron and mercury accounted for 50% of the exceedances of chronic criteria (most were iron values, 81%). Other heavy metals for which some sample concentrations exceeded acute and chronic freshwater aquatic life criteria were cadmium, copper, lead, zinc, and silver. In general, long-term trends of major metals and trace elements in water displayed little consistency (Jordan and Stamer 1991). Of the heavy metal species tested by Jordan and Stamer for time trends, only total copper (positive trend for one site on Big Blue River) and total zinc (negative trend for one site on lower Kansas River) were listed as having statistically significant trends (Table 3). Whole-fish samples analyzed for heavy metals revealed that median and 90th percentile tissue concentrations of cadmium, copper, and zinc in fish from the lower Kansas River were greater than nationwide values (Jordan and Stamer 1991). These authors did not observe any relations between fish whole-body burden and sediment or water sample concentrations. Accumulation of copper, zinc, and lead by some aquatic insect species in the lower Kansas River was observed by Marzolf (1979). Unfortunately, Marzolf's data do not provide exposure values (concentration value for sediment or water) or enough other data (e.g., hardness concentration) needed to estimate acute or chronic exposure values. Based on the available data, we cannot determine the sources of heavy metals nor their overall effect on Kansas River flora or fauna. Trace elements or heavy metal concentrations infrequently impose chronic effects on some faunal elements of the river's existing ecosystems.

Pesticides

Anthropogenic organic compounds found in the lower Kansas River basin (except domestic sewage) consist mostly of pesticides. This is not surprising, considering the low industrial but intensive agricultural development that has occurred throughout the lower basin and most of the upper basin. Typically, human-made organic compounds, other than pesticides, are seldom found except for localized occurrences. Jordan and Stamer (1991) listed 21 pesticides that have occurred in 10 or more water samples from streams in the lower Kansas River basin. The data compiled by these researchers show that no detected pesticide concentration exceeded acute freshwater aquatic life criteria (U.S. Environmental Protection Agency 1987); however, chronic aquatic life criteria and river concentrations were not compared by these authors. In addition, multiple toxicity responses are often of great concern (Anderson and d'Appollonia 1978; Marking 1985; Blackburn 1987), and much higher exposures (concentrations) are associated with runoff events (Baker et al. 1985), which are seldom sampled. Baker and coworkers also pointed out that peak concentrations (high values) of agricultural chemicals (i.e., pesticides) are associated with watershed size. All things being equal, as watershed size decreases, the peak concentrations of suspended sediments, nutrients, and pesticides increase. Thus, pesticide concentrations noted in the Kansas River or other large rivers are probably much lower than concentrations in the small-order (orders 1–5) streams that compose most of the drainage network of the basin. Conversely, the duration of exposure is longer in large streams than in small streams (Fig. 4; Baker et al. 1985). Unfortunately, few pesticide data are available for the smaller tributaries of the Kansas River; however, agrichemical concentrations in these aquatic ecosystems are probably high but erratic in occurrence.

Chlorinated insecticides and polychlorinated biphenyls (PCBs) were more frequently found in streambed sediment than in water samples from the lower Kansas River basin (Jordan and Stamer 1991). This is probably related to their low solubility in water and tendency to adhere to sediments and organic matter. These compounds are known to accumulate in sediment and aquatic organisms (mostly in fatty tissues; Khan 1977; Smith et al. 1988). Jordan and Stamer indicated that observed concentrations of chlorinated insecticides and PCBs in streamwater and sediment samples were below established aquatic life criteria. However, they cautioned that existing criteria do not consider potential toxic effects originating from multiple or joint exposure to these and other anthropogenic compounds that are known to occur in the river system.

The occurrences of organophosphorus insecticides (e.g., parathion, diazinon) in the lower Kansas River basin also seemed to be limited, but several authors have shown that herbicides are frequently found in the waters of the basin (Butler and Arruda 1985; Jordan and Stamer 1991). Butler and Arruda found that no samples collected before 1977 as part of Kansas' Ambient Stream Water Quality Network contained detectable concentrations of pesticides, but since then the occurrences of herbicides have become common in Kansas waters (Kansas Department of Health Environment 1988). Atrazine and alachlor were the most frequently detected herbicides in the lower Kansas River basin, often occurring throughout the year except for winter months (alachlor; Jordan and Stamer 1991). Over one-half of the water samples taken in June contained atrazine levels above the U.S. EPA drinking water criteria (3 mg/L). Less frequent sample exceedances were observed for alachlor. Other herbicides associated with the waters of many upper midwestern river systems were atrazine metabolites, cyanazine, metalochlor, metribuzin, and simazine (Butler and Arruda 1985; Kansas Department of Health Environment 1988; Goolsby and Thurman 1990; Jordan and Stamer 1991; Thurman et al. 1991). Available data from these researchers indicate that high stream concentrations are most often found during periods of runoff following cropland application. The ecological effects of herbicide contamination of the lower Kansas River basin have not been quantified, and aquatic life criteria or guidelines for most herbicides found in basin waters do not exist. However, many researchers have suggested environmental effects from herbicides on aquatic resources (Butler and Arruda 1985; Kansas Department of Health Environment 1989; Huggins 1990).

Bacteria

Nearly all available information concerning the structure and function of microbial communities of the streams and rivers of the Kansas River basin pertains to fecal-indicator bacteria. Naturally occurring microbial communities influence biochemical reactions, promote organic decomposition, and are often the primary group responsible for energy transformations in large streams and rivers (Vannote et al. 1980; Lock and Williams 1981). In addition, the microbial food webs of freshwater aquatic ecosystems are now recognized as important pathways for energy flow in these systems (Stockner and Porter 1988). Only Marzolf (1979) provided any insights into the function of microbial populations in the ecology of the Kansas River. Seemingly, the Kansas River can switch from an autotrophic (primary production influence) to a heterotrophic system (microbial influenced), depending on local and general stream conditions. Marchin and Upton (1990) indicated that several waterborne pathogens (e.g., *Girardia, Salmonella*) can be found in the Kansas River and its reservoirs, and they warned against drinking raw water. Neither the study by Marzolf (1979) nor Marchin and Upton (1990) was capable of relating current conditions with past conditions (assuming historic data exist).

Fecal coliform bacteria densities in the lower Kansas River basin (mainly the Blue River) sometimes exceeded the secondary-contact recreational use criteria established by Kansas Department of Health and Environment. Exceedances were typically limited to stream reaches downstream from wastewater treatment facilities (Jordan and Stamer 1991). They reported significant time trends of flow-adjusted fecal coliform densities at 2 of 11 lower Kansas River stations (Table 3). These two stations had decreasing trends in fecal coliform densities, as did eight of the nine stations for which nonsignificant time trend results (flow-adjusted density values) were presented by Jordan and Stamer (1991). They speculated that general reductions in fecal coliform densities might be related to similar decreases in suspended sediments. Significant time trends for fecal streptococci densities were identified at three of five stations located in the Kansas River

basin (Jordan and Stamer 1991). Trend-test results revealed the presence of positive and negative trends (Table 3).

Invertebrate Communities

Photosynthetic Producers

Aside from reservoir research, only localized studies of relative short duration have been done on the major tributaries and mainstem of the Kansas River. This is also true for most other invertebrate groups except for statewide macroinvertebrate monitoring programs established by Kansas Department of Health Environment (1972 to present) and Nebraska Department of Environmental Control (1985–86 collections for Blue River basin). Little historic information was found on the invertebrate biota that inhabited the Kansas River and its tributaries before the 1960's. Aquatic vascular plants are rare in mainstem reservoirs and currently are so rare in the Kansas River and its tributaries that as a group they cannot be considered as a functional entity of the river ecosystem. Photosynthetic production in this river system is solely attributed to the algal communities (planktonic and benthic) that reside in these streams.

Seasonal variations in total photosynthetic production in the Kansas River were examined by Marzolf (1979), who concluded that the maximum photosynthetic production of this river was very high (30 g C/m^2/day), exceeding most eutrophic lake values by sixfold. He was able to demonstrate that benthic algal populations were the primary source of planktonic chlorophyll and that flow history of the river determines planktonic chlorophyll concentration. Marzolf found that plankton released from Milford Reservoir added very little planktonic chlorophyll to the river, probably because Kansas River reservoirs typically have low chlorophyll concentrations (Marzolf and Osborne 1972; O'Brien 1975), and lake plankton is often rapidly removed from rivers (Chandler 1937; Neel et al. 1963). Marzolf (1979) observed that reservoir releases generally reduced planktonic chlorophyll concentrations in the river, and speculated that this resulted from dilution, increased turbidity caused by bank erosion, and removal of algal populations near the water's edge by deeper, faster flow. Although benthic algal mats were eroded by increased flow, this was not sufficient to increase planktonic chlorophyll values.

These findings, along with other elements of Marzolf's research, led him to several important discoveries concerning the primary productivity of the Kansas River under recent conditions. First, photosynthetic production (planktonic and benthic) and the trophic character of the river fluctuate with discharge and turbidity. Because of the variable flow patterns and high nutrient concentrations associated with the river, channel morphology and trophogenic regime determine photosynthetic production within the river. Second, maximum photosynthetic production estimates and other supportive data indicate that the lower river system is potentially so highly productive and biologically active that biological processes are likely to have significant influences on chemical water quality.

The general findings of Marzolf (1979) were partially corroborated by Cross et al. (1982) in their study of the effects of sand and gravel dredging in the Kansas River reach upstream from Kansas City. While these researchers did not estimate photosynthetic production, phytoplankton counts were highest under low flow conditions, and mats of benthic algae were observed to develop in shallowwater areas during low flows. They observed few changes in the phytoplankton community that were caused by dredging activity, but indicated that species composition or abundance changed seasonally or "in periods of high discharge from lakes, which added a new contingent of organisms to the community." Examination of their data was relatively inconclusive, but comparisons of months for which phytoplankton counts and discharge were available (1979–81) show that the highest phytoplankton cell counts were associated with monthly periods of low, stable (discharge), or decreasing flow when compared with months of high flow or periods of both increasing and decreasing flow (Table 23 in Cross et al. 1982).

Typical planktonic algae genera observed in the lower Kansas River were *Cyclotella, Stichococcus, Synedra, Scenedesmus, Melosira, Actinastrum, Chlamydomonas, and Coelastrum,* while filamentous chlorophyta and cyanophyta dominated observed benthic algal mats (Cross et al. 1982). Historic data for the Kansas River and tributaries were not located, but pre- and post-impoundment data for the central Missouri River showed phytoplankton abundances were much higher after reservoir construction (Benson 1968; Benson and Cowell 1968). These authors did not indicate

whether phytosynthetic production (either planktonic or benthic) in free-flowing sections of the Missouri River had increased or decreased because of reservoir construction. Their data indicate that reservoirs have increased phytoplankton numbers in the Missouri River, but this may not be so in the Kansas River, based on Marzolf's (1979) findings. Plankton addition to the river from reservoir release water may not be the significant factor involved in the noted higher river phytoplankton values observed after impoundment (Cross and Moss 1987). Stable flows and constant influx of nutrients to stream reaches below impoundments may be contributing to elevated algal production in the stream channel. While nearly one-third of the Missouri River has been impounded (Hesse et al. 1989), the mainstem Kansas River is still free flowing.

In summary, the available but limited data for the mainstem of the Kansas River indicate that under stable flow regimes the river is highly productive and that plankton in reservoir release water do not have a large positive effect on chlorophyll concentrations of the river. Actually, reservoir releases tend to reduce photosynthetic production in the river (Marzolf 1979).

Zooplankton

Zooplankton data for the mainstem and major tributaries of the Kansas River are extremely limited. Cross et al. (1982), who studied the effects of dredging on the lower Kansas River, found that cyclopoid copepods were the major zooplankton constituent. Calanoid copepods were generally present in low numbers, and ostracods were rarely found during their study. Dredging activities had little effect on river zooplankton abundances (Cross et al. 1982). Monthly estimates of zooplankton densities in the lower Kansas River varied from 2 to 4,880 organisms/m^3 (calculated from data in Cross et al. 1982), whereas mean monthly density values for the lower Missouri River ranged from 7 to 345/m^3 (Repsys and Rogers 1982). No information on the direct effects of Kansas Basin reservoirs on river zooplankton populations could be located.

Macroinvertebrates

The Kansas River and its major tributaries consist mainly of shifting-sand habitats supplemented by rare riffle areas of gravel or larger substrate and occasional depositional areas (e.g., pools or backwater). In general, this river system can be characterized as having a shifting-sand bottom, low levels of light penetration, and a fluctuating discharge during much or all of the year. In many river reaches, discharge is less variable now than in the past because of regulated flow imposed by reservoirs on the primary tributaries of the Kansas River. While rivers with bottoms of shifting sand can be found throughout the world, the insect fauna of these rivers is remarkably uniform (Barton and Smith 1984), being characterized by sand-dwelling species of Diptera, Ephemeroptera, and Odonata. The psamophilic fauna is but one of several faunal associations found in the Kansas River and its tributaries. Other observed associations include edge communities inhabiting submerged terrestrial vegetation, roots, and wetted shorelines; depositional assemblages common to areas characterized by accumulated silt and organic debris; and the fauna of "snag" habitats, which are composed of large woody material (limbs, logs, and associated detritus) and the epirheic zone of Ferrington and Goldhammer (1993). The "epirheic zone" consists of elevated areas of the capillary fringe zone, that is, bars and banks in the channel that remain moist to a higher level than the stream surface because of capillary action. Few of these Kansas River invertebrate communities have been studied in detail. Most studies have been limited by sampling methods that sample only a single or partial habitat (e.g., shallow riffles), although varied habitats occur within the river system and distinct macroinvertebrate-substrate relationships are well defined (Cummins et al. 1966; Minshall 1984). As no historic or current monitoring (or research) efforts have attempted to incorporate a comprehensive sampling approach, little can be said about macroinvertebrates that might have occurred basinwide.

The statewide macroinvertebrate monitoring efforts of Kansas Department of Health and Environment (1972 to present), which have included numerous stations on the Kansas River and its tributaries, have led to few conclusions concerning the status of the macroinvertebrate community in this basin (Kansas Department of Health and Environment 1986, 1988, 1990). Jordan and Stamer (1991) summarized the findings of Kansas Department of Health and Environment and Nebraska Department of Environmental Control for the lower Kansas River basin. Their assessment of these data led them to conclude that the Big Blue

River had a somewhat healthier benthic community than the Little Blue River in Nebraska, whereas the Kansas portions of the lower basin supported only slightly impaired communities. In general, current monitoring efforts within the Kansas River basin have been relatively ineffective in relating macroinvertebrate data to historic or current water quality or habitat conditions. Many site-specific studies confine their examination of macroinvertebrates to some portion of the invertebrate community and often fail to measure concurrent habitat or water quality conditions necessary to establish probable cause and effect relations. However, we present the data or results of several noteworthy studies to characterize macroinvertebrate assemblages found on the Kansas River and to provide insight into some changes that probably have occurred during the last century.

The freshwater mussels (Mollusca: Pelecypoda) of the Kansas River basin represent the single macroinvertebrate group for which truly historic data are available. Comparisons of the published mussel data for Kansas that were compiled by Call (1885, 1886, 1887), Scammon (1906), and Murray and Leonard (1962), and the more recent collections (1972–80) of the Kansas Biological Survey (University of Kansas, Lawrence), indicate that many unusual species no longer inhabit the mainstem of the Kansas River (Table 4). About 13 species of freshwater mussels seem to have occurred in the Kansas River based on a review of Call's (1885, 1887) list in the late 1800's. Identification of several of the species reported by Call was questioned by later researchers (Murray and Leonard 1962), and we have excluded these species (e.g., *Fusconias ebena*) from our list, creating a somewhat conservative estimate of the early mussel fauna.

Recent efforts by the Kansas Biological Survey (1972–80) and a review of earlier work (Murray and Leonard 1962) indicate that only four mussel species occur at present within the mainstem of the Kansas River, while 11 of 13 species reported by Call as occurring in the Kansas River still inhabit its tributaries. We cannot at this time offer any hypothesis as to why so many species have disappeared from the mainstem but have maintained themselves to a greater or lesser extent in some tributaries. Some species that were historically common in the basin are now rare. For example, Scammon (1906) listed *Potamilis alatus* as common in the Kansas River drainage, but current observations are extremely rare. The basinwide status of many other species historically known from the Kansas River remains unclear, but the impoundments that now exist on all major tributaries and the increased presence of toxicants in the river are reasons for concern (Murray and Leonard 1962; Oesch 1984). Conversely, at least two species that were rarely collected from the Kansas River have increased in abundance and distribution within the mainstem and its major

Table 4. Historic and current occurrences (X) of freshwater Mollusca:Pelecypoda that were originally reported from the mainstem of the Kansas River basin. Occurrences of these river species in the tributaries of the lower basin are also noted. Historic occurrences are based on Call's collections (Call 1885, 1886, 1887), and current records refer to the Kansas Biological Survey collections of 1972-80. Mussel nomenclature follows that of American Fisheries Society Special Publication 16 (Turgeon et al. 1988).

		Historic		Current	
Common name	Scientific name	Mainstem	Tributaries	Mainstem	Tributaries
Pink papershell	*Potamilus ohioensis*	X	X	X	X
Pink heelsplitter	*P. alatus*	X	X		X
Bleufer	*P. purpuratus*	X	X		X
Fatmucket	*Lampsilis siliquoidea*	X	X	X	X
Pocketbook	*L. ovata*	X	X		X
Wabash pigtoe	*Fusconaia flava*	X	X		X
Hickorynut	*Obovaria olivaria*	X			
Fragile papershell	*Leptodea fragilis*	X	X	X	X
Threeridge	*Amblema plicata*	X	X		X
Pimpleback	*Quadrula pustulosa*	X	X		X
Giant Floater	*Anodonta grandis*	X	X	X	X
Mucket	*Actinonaias ligamentina*	X	X		
Fawnsfoot	*Truncilla domaciformis*	X	X		X

tributaries. While few or no occurrences of *Anodonta grandis* and *Potomilus ohioensis* were recorded by earlier researchers (Call 1887; Scammon 1906), recent collections by the Kansas Biological Survey (1972–80) from the Kansas River indicate that these two species are now the most common mussels found in the mainstem and western tributaries.

Obovaria olivaria and *Actinonaias ligamentina* are no longer found in the Kansas River basin (Table 4). Scammon (1906) also listed *O. olivaria* as common in eastern Kansas, where it preferred the moderately deep water of sandy-bottomed streams. Subsequent to Call and Scammon's findings no recent records of this species were collected, prompting Murray and Leonard (1962) to list it as extirpated in Kansas. *Actinonaias ligamentina* was apparently never common in the Kansas River or its tributaries but was frequently taken in the Marais des Cygnes River (a southeastern Kansas drainage) by Scammon (1906). This species can still be found in several of the river systems of southeastern Kansas (Murray and Leonard 1962; Liechti and Huggins 1977; Schuster and DuBois 1979). Oesch (1984) stated that in Missouri this species prefers stable gravel bottoms in rivers, whereas Murray and Leonard (1962) indicated that it was found in all types of river substrate from cobble to sand.

In summary, available information on the historic and current mussel fauna of the Kansas River indicates that two species have not been reported from the basin and many others have disappeared from the mainstem of the river since 1962. The reasons for these apparent losses are unknown.

Current studies of one Kansas River macroinvertebrate community indicate that the epirheic community has been severely affected. Ferrington and Goldhammer (1993) determined that the epirheic zone of the Kansas River was a discrete habitat that is utilized by aquatic organisms throughout their life cycles. Their finding is in contrast to the earlier views of Williams and Hynes (1977), who suggested that the epirheic zone was used only as a refuge for some aquatic species during periods of low flow. The epirheic fauna of the Kansas River was dominated by habitat generalists, and many of the macroinvertebrate taxa of this zone and other river habitats of the openwater zone were indicative of affected waters (Ferrington and Goldhammer 1993). These authors speculated that the existing epirheic zone fauna has been severely affected by stream impoundments which altered flow patterns in the river, and municipal effluents that have led to nutrient enrichment. Goldhammer and Ferrington (1992) compared the epirheic zone associated with a near-pristine reach of the Cimarron River (Benke 1990) and that of the Kansas River. They concluded that flow regulation and effluent discharges have altered the Kansas River to such an extent that the specialist taxa of epirheic and openwater habitats common in a free-flowing river (i.e., Cimarron River) have been eradicated or severely reduced and replaced by generalist species.

Most macroinvertebrate studies of the Kansas River have focused on aquatic insects and other small-sized invertebrates (e.g., snails, fingernail clams, oligochaetes). Quantitative approaches typically utilize bottom samplers, artificial substrate samplers, or drift nets. The benthic invertebrate assessment of river dredging operations on the lower Kansas River perhaps best illustrates the nature of the benthic community in open reaches of the river: Cross et al. (1982) recorded 56 aquatic invertebrate taxa collected from drift and bottom samples (portable invertebrate box sampler, PIBS) during their 3-year study, in which S. L. Dewey performed macroinvertebrate identifications and analyses. Of the 28 common taxa, midge (Diptera: Chironomidae) and caddisfly (Trichoptera) larvae were the numerically dominant aquatic insects at all sites (control and dredge sites). Larvae of *Potamyia, Hydropsyche,* and *Chematopsyche* were the most abundant caddisflies collected and are common throughout the lower river, where large aggregations can be observed on submerged logs and other debris. Cross et al. (1982) listed 11 mayfly (Ephemeroptera) genera as common (e.g., *Isonychia, Stenonema, Stenacron, Heptagenia, Hexagenia, Centroptilum, Tricorythodes, Pentagenia, Ephoron, Caenis, Baetis*) and 6 as rare (e.g., *Apobaetis, Homoeoneuria, Brachycentrus, Potamanthus, Choroterpes, Tortopus*). *Apobaetis* and *Homoeoneuria* larvae live only in lotic, shifting-sand environments (Barton and Smith 1984). Other common aquatic insects identified in the dredge study of Cross et al. (1982) were burrowing dragonfly larvae (*Gomphus*), *Argia* (Odonata: Coenagrionidae), the riffle beetle *Stenelmis, Trichocorixa* (Hemiptera: Corixidae), ceratopogonid larvae, and several stonefly genera (i.e., *Neoperla, Perlesta, Isoperla*). Aquatic earthworms (Oligochaeta), snails of the genus *Physa,* and fingernail clams (Sphaeriidae) were the most common noninsect groups.

An additional 28 taxa were reported as rare (<5 individuals/sample) by Cross et al. (1982). Most of these taxa were aquatic insects, including members of several dipteran families (Chaoboridae, Empididae, Ephydridae, Tipulidae), three genera of aquatic and semiaquatic Hemiptera (i.e., *Notonecta, Neoplea, Rhagovelia*), *Corydalus* (Megaloptera), *Sialis* (aquatic Neuroptera), and several genera of Odonata and Trichoptera. Of special interest was their discovery of the Asian clam *Corbicula* (Corbiculidae). Since the report by Cross et al. (1982), this nuisance organism has been found to occur in small populations throughout the lower river and is well established in some of the Kansas River basin reservoirs as far west as Cedar Bluff on the Smoky Hill River (Mackie and Huggins 1983).

Cross et al. (1982) summarized the substrate associations (i.e., lotic erosional, lotic depositional) of the Kansas River invertebrate taxa collected from their study sites. Twenty-two taxa were classified as occurring only in depositional areas characterized by silts and fine sands, 15 taxa were associated with erosional conditions (coarse sediment, gravel, rubble, fast current), and 17 taxa were not associated with a specific habitat condition. These findings indicate that within the stream channel a variety of habitat conditions can exist and are utilized by macroinvertebrates, given the opportunity. The initial effect of dredging promoted short-term development of erosional and depositional habitat, such that control sites had fewer taxa (20) and lower densities ($32/m^2$) of benthic organisms than dredge sites (Cross et al. 1982). Diversity Values (Shannon-Wiener's H') for control and dredge site samples (bottom grab sampler) displayed both temporal (annual) and spatial variations, ranging from a high of 0.92 (control) to a minimum of 0.44 (dredge site). As water quality at all sites was similar, substrate diversity and composition seemed to be the major factor affecting benthic communities.

In fact, the invertebrate fauna of the Kansas River is richer and more diverse than the results of Cross et al. (1982) would indicate. The aquatic invertebrate research collection of the Kansas Biological Survey contains many additional invertebrate records from the Kansas River and its major tributaries. An initial search of aquatic insect records in Kansas Biological Survey collection indicates that 11 Plecoptera genera, 9 Odonata, 20 Ephemeroptera, 6 Trichoptera, 36 or more Diptera, 8 to 10 Coleoptera, 4 or more aquatic and semiaquatic Hemiptera, and perhaps 2 or more Megaloptera and aquatic Neuroptera—an estimated 96 genera of aquatic insects—occur in the major rivers of the Kansas River basin. The number of genera of noninsect invertebrates inhabiting the river is probably greater than 20. Many of these records were published in the Kansas Biological Survey Technical Publication Series between 1977 and 1981, and all specimens are housed in the aquatic invertebrate collection in Foley Hall (University of Kansas, Lawrence).

At present, only one aquatic invertebrate in the basin is regarded as endangered or threatened. *Optioservus phaeus* (Coleoptera: Elmidae) is currently listed by Kansas as endangered and is a federal candidate species.

Fish Communities

Ancient Freshwater Fauna

Fossil fishes are known from 11 localities in the area now drained by the Kansas River (Cross et al. 1986). Two Miocene faunas (8–10 million years ago) consist of 12 taxa in the genera *Amia, Lepisosteus, Notropis* (2), *Ictiobus, Ictalurus* (2), *Fundulus* (2), *Micropterus, Lepomis,* and *Pomoxis.* Faunas from nine other sites vary in age from 0.1 to more than 2.0 mya, spanning the last glacial epoch. Most of the 28 taxa reported from those sites still inhabit the Kansas River basin. One (*Ictalurus sawrockensis*) is extinct, two (mountain sucker, *Catostomus platyrhynchus; "Noturus furiosus* group") have been extirpated from this basin but persist elsewhere, and three (a species of dace, *Rhinichthys spp.;* walleye, *Stizostedion vitreum;* yellow perch, *Perca flavescens*) were extirpated but have been reintroduced.

Recent Fauna

Seventy to 75 species of fish inhabited the Kansas River basin in the latter part of the nineteenth century, when the first useful distributional records were obtained. The indigenous fauna (Table 5) consisted of geographically and ecologically different communities of species, as well as several species that were nearly ubiquitous (Smith and Fisher 1970; Hawkes et al. 1986). No species were endemic to the Kansas River basin, but several species had their southwestern distributional limits in this drainage system. Stocks of at least

24 species have been introduced into the basin, some so early that a possibility exists that they also occurred naturally (accounting for uncertainty as to the exact number of native species).

Large, sight-feeding piscivores were rare or absent in the Kansas River system. Catfishes and gars were the principal predators, and large fishes were confined to the eastern part of the basin. Blue catfish, pallid sturgeon, paddlefish, and occasional lake sturgeon and burbot occurred in the lowermost Kansas River, some or all as spring migrants from Missouri River. Buffalofishes and blue catfish were important commercial food fish in the lower Kansas River until about 1920. Most blue catfish were caught in June in hoop nets—sometimes hundreds of kilograms of fish weighing more than 16 kg each in one net on one night (Dyche 1914; Cross 1967). These species declined

Table 5. Distributional status of fishes in the Kansas River basin. Regions are mapped in Fig. 3.

Common name	Scientific name	High Plains	Smoky Hills	Flint Hills	Glaciated Region	Osage Cuestas	Mainstem & flood plain[a]
Chestnut lamprey	*Ichthyomyzon castaneus*	—	—	—	—	E[b]	E
Lake sturgeon	*Acipenser fulvescens*	—	—	—	—	—	R[c]
Shovelnose sturgeon	*Scaphirhynchus platorynchus*	—	N[d]	—	—	—	N
Pallid sturgeon	*S. albus*	—	—	—	—	—	E
Paddlefish	*Polyodon spathula*	—	—	—	—	R	R
Shortnose gar	*Lepisosteus platostomus*	—	R	—	—	—	N
Longnose gar	*L. osseus*	—	N	N	N	N	N
American eel	*Anguilla rostrata*	E	E	—	—	—	E
Skipjack herring	*Alosa chrysochloris*	—	—	—	—	—	I
Gizzard shad	*Dorosoma cepedianum*	I[e]	I	N	N	N	N
Goldeye	*Hiodon alosoides*	—	R	—	—	N	N
Brook trout	*Salvelinus fontinalis*	I	—	—	—	—	—
Brown trout	*Salmo trutta*	I	I	I	—	—	—
Rainbow trout	*Oncorhynchus mykiss*	I	I	I	—	—	—
Northern pike	*Esox lucius*	I	I	I	I	I	I
Common carp	*Cyprinus carpio*	I	I	I	I	I	I
Goldfish	*Carassius auratus*	I	I	I	I	I	I
Grass carp	*Ctenopharyngodon idella*	I	I	I	I	I	—
Rudd	*Scardinius erythrophthalmus*	—	I	I	I	I	I
Golden shiner	*Notemigonus crysoleucas*	I	I	I	N	N	N
Creek chub	*Semotilus atromaculatus*	N	N	N	N	N	N
Southern redbelly dace	*Phoxinus erythrogaster*	E	—	N	—	—	—
Longnose dace	*Rhinichthys cataractae*	I	—	—	—	—	—
Flathead chub	*Platygobio gracilis*	E	E	—	—	—	E
Hornyhead chub	*Nocomis biguttatus*	E	E	E	—	E	E
Silver chub	*Macrhybopsis storeriana*	E	E	—	—	—	N
Speckled chub	*M. aestivalis*	E	E	E	—	—	N
Sicklefin chub	*M. meeki*	—	—	—	—	—	E
Sturgeon chub	*M. gelida*	E	E	—	—	—	E
Suckermouth minnow	*Phenacobius mirabilis*	N	N	N	N	N	N
Emerald shiner	*Notropis atherinoides*	—	E	—	—	—	N
Rosyface shiner	*N. rubellus*	—	—	N	—	—	R
Silverband shiner	*N. shumardi*	—	—	—	—	—	E
River shiner	*N. blennius*	E	—	—	—	—	R
Topeka shiner	*N. topeka*	E	E	N	E	E	—
Bigmouth shiner	*N. dorsalis*	—	—	—	N	—	R
Sand shiner	*N. stramineus*	N	N	N	N	N	N
Ghost shiner	*N. buchanani*	—	—	—	—	—	E
Blacknose shiner	*N. heterolepis*	E	—	—	—	—	—
Redfin shiner	*Lythrurus umbratilis*	E	E	N	R	N	R
Common shiner	*Luxilus cornutus*	E	E	N	—	E	—
Red shiner	*Cyprinella lutrensis*	N	N	N	N	N	N

Table 5. *Continued.*

Common name	Scientific name	High Plains	Smoky Hills	Flint Hills	Glaciated Region	Osage Cuestas	Mainstem & flood plain[a]
Brassy minnow	*Hybognathus hankinsoni*	E	E	—	—	—	—
Plains minnow	*H. placitus*	E	E	E	E	—	E
Western silvery minnow	*H. argyritis*	—	—	—	—	—	E
Fathead minnow	*Pimephales promelas*	N	N	N	N	N	N
Bullhead minnow	*P. vigilax*	—	I	I	I	I	I
Bluntnose minnow	*P. notatus*	R	R	N	N	N	R
Central stoneroller	*Campostoma anomalum*	N	N	N	N	N	R
Blue sucker	*Cycleptus elongatus*	—	—	—	—	—	R
Bigmouth buffalo	*Ictiobus cyprinellus*	—	I	N	—	—	N
Black buffalo	*I. niger*	—	—	N	—	—	N
Smallmouth buffalo	*I. bubalus*	—	I	N	—	—	N
Quillback	*Carpiodes cyprinus*	R	N	R	—	—	N
River carpsucker	*C. carpio*	N	N	N	N	N	N
Highfin carpsucker	*C. velifer*	—	—	E	—	E	E
Spotted sucker	*Minytrema melanops*	—	—	E	—	—	—
Golden redhorse	*Moxostoma erythrurum*	—	—	R	—	—	—
River redhorse	*M. carinatum*	—	—	—	—	E	—
Shorthead redhorse	*M. macrolepidotum*	—	R	N	—	R	N
White sucker	*Catostomus commersoni*	N	E	N	N	N	R
Longnose sucker	*C. catostomus*	I	—	—	—	—	—
Black bullhead	*Ameiurus melas*	N	N	N	N	N	N
Brown bullhead	*A. nebulosus*	—	—	I	I	I	—
Yellow bullhead	*A. natalis*	I	I	N	R	N	R
Channel catfish	*Ictalurus punctatus*	R	N	N	N	N	N
Blue catfish	*I. furcatus*	—	—	I	—	—	R
Flathead catfish	*Pylodictis olivaris*	I	I	N	N	N	N
Tadpole madtom	*Noturus gyrinus*	—	—	—	R	—	—
Slender madtom	*N. exilis*	—	—	N	—	N	—
Stonecat	*N. flavus*	E	E	N	R	N	N
Burbot	*Lota lota*	—	—	—	—	—	E
Plains topminnow	*Fundulus sciadicus*	I	—	—	—	—	—
Plains killifish	*F. zebrinus*	E	E	—	—	—	R
Western mosquitofish	*Gambusia affinis*	—	I	I	I	I	I
White bass	*M. chrysops*	I	I	I	I	I	N
Striped bass	*M. saxatilis*	I	I	I	—	I	I
Smallmouth bass	*Micropterus dolomieu*	I	I	I	I	I	—
Spotted bass	*M. punctulatus*	I	I	I	I	I	—
Largemouth bass	*M. salmoides*	I	I	N	N	N	N
Warmouth	*Lepomis gulosus*	—	I	—	—	R	R
Green sunfish	*L. cyanellus*	N	N	N	N	N	N
Redear sunfish	*L. microlophus*	—	I	I	I	I	—
Pumpkinseed	*L. gibbosus*	—	—	—	—	I	—
Bluegill	*L. macrochirus*	I	I	N	N	N	N
Orangespotted sunfish	*L. humilis*	N	N	N	N	N	N
Longear sunfish	*L. megalotis*	—	—	N	—	R	—
Rock bass	*Ambloplites rupestris*	I	I	I	—	I	—
White crappie	*Pomoxis annularis*	I	I	N	N	N	N
Black crappie	*P. nigromaculatus*	I	I	I	I	I	I
Walleye	*Stizostedion vitreum*	I	I	R	I	I	I
Sauger	*S. canadense*	—	—	R	—	—	R
Yellow perch	*Perca flavescens*	I	I	I	I	I	I
Blackside darter	*Percina maculata*	—	—	E	—	—	—
Logperch	*P. caprodes*	—	R	N	R	N	R
Johnny darter	*Etheostoma nigrum*	E	E	N	R	N	R

Table 5. *Continued.*

Common name	Scientific name	High Plains	Smoky Hills	Flint Hills	Glaciated Region	Osage Cuestas	Mainstem & flood plain[a]
Orangethroat darter	*E. spectabile*	E	E	N	N	N	R
Tilapia	*Tilapia* spp.	—	I	—	I	—	—
Freshwater drum	*Aplodinotus grunniens*	I	I	N	I	I	N

[a] Kansas River and lowermost parts of its tributaries.
[b] E = endangered or extirpated (native but depleted).
[c] R = rare (native, but unlike E, not recently depleted).
[d] N = native populations stable or increasing.
[e] I = introduced or invasive.

or disappeared in the early 1900's. Commercial fishing in the Kansas River was outlawed in 1923, but populations of the species listed did not soon recover.

About 30 other species occurred only in streams east of 99° longitude (Table 5). Most of the remaining native fishes ranged throughout the basin, although a few (river shiner, brassy minnow, and plains killifish) were predominantly western. Two species (pallid sturgeon and sicklefin chub) are endangered (federal and state lists), and 14 others are currently listed by the Kansas Department of Wildlife and Parks as threatened or in need of conservation in Kansas.

High Plains Province

Fishes in the western half of the basin (the High Plains region) comprised two major guilds. One of these occupied streams that were usually clear, with relatively constant base flows sustained by high water tables in the Ogallala aquifer. Their well-defined channels had pools, some with submerged macrophytes, and stable substrates with gravel as well as coarse sand and silt. Species characteristic of these streams were creek chub, hornyhead chub, stoneroller, common shiner, Topeka shiner, brassy minnow, bluntnose minnow, white sucker, orangethroat darter, and Johnny darter. Southern redbelly dace (Hay 1887) and blacknose shiner (Hubbs 1951) apparently inhabited a few of these streams before settlement. The fishes in this guild need cool temperatures and clear water, significant autochthonous food-production (plankton, aufwuchs, insects associated with firm substrates or macrophytes), and gravel substrates for reproduction. No species found in the western Kansas River basin were obligate riffle fishes; all species in this guild are able to persist in pools, and most prefer pool habitat.

The second guild in the western area inhabited aggraded streams with widely fluctuating, turbid flow, and unstable sand substrates. Species characteristic of this habitat were speckled chub, sturgeon chub, flathead chub, silver chub, plains minnow, and river carpsucker.

Other, more widespread species, less indicative of specific macrohabitats than those noted above, included the suckermouth minnow, red shiner, sand shiner, river shiner, fathead minnow, black bullhead, stonecat, green sunfish, and orangespotted sunfish. Channel catfish, goldeye, and American eel occurred in some of the larger streams (Breukelman 1940) and were, together with green sunfish and orangespotted sunfish, the main "top carnivores" in the western fauna.

The accounts in paragraphs above are based on nineteenth century conditions in the upper Smoky Hill, Saline, and Solomon drainages in northwestern Kansas; they are from records of several collections in that area by Hay (1887) and associates of F. W. Cragin at Washburn University (Gilbert 1884–86, 1889; Cragin 1885). Their records provided the earliest reasonably comprehensive information about the fish fauna of the region before its extensive modification by agricultural development. Later surveys of fishes in this part of the basin were reported by Breukelman (1940), Metcalf (1966), Summerfelt (1967), Kansas Department of Health and Environment (1978), Tomelleri et al. (1986), and Eberle et al. (1989). Cross and Moss (1987) summarized historic changes in the fauna, mainly extirpation of species that were most characteristic of the clear-tributary and turbid-river guilds. Some small-stream fishes disappeared during early stages of settlement, probably because of siltation following cultivation, and di-

version of water from springs. But, much of the depletion has been recent, resulting from progressive drying of streams because of drought, irrigation, and land-use practices that retard runoff. At some sites, as many as three-fourths of the species captured by Hay (1887) in 1885 had disappeared by 1985 (Cross and Moss 1987). All studies of fishes in this region and elsewhere in the Kansas River basin have emphasized species composition (richness). Precise information on abundance has seldom been recorded, and then only in field notes or unpublished tabular reports of the collectors. Therefore, diversity index values for fish communities generally are not accessible. Summerfelt (1967) is exceptional; that report contains diversity index values for collections made at several localities in the Smoky Hill River in 1965 and 1966, calculated in a manner not currently used for diversity index determination. Converted to Shannon–Wiener (H') values, diversity indices for Summerfelt's collections at six sites in July 1965 and 1966 vary from 1.24 to 2.00 (average 1.68).

In 1977, fishes in the westernmost, headwater streams of the basin in Colorado were surveyed by Cancalosi (1981). He reported 24 species, 14 of which were native, in declining order of abundance: sand shiner, orangethroat darter, stoneroller, fathead minnow, creek chub, plains killifish, white sucker, brassy minnow, red shiner, plains minnow, river shiner, black bullhead, suckermouth minnow, and stonecat. The 10 introduced species were rainbow trout, brown trout, common carp, goldfish, channel catfish, largemouth bass, green sunfish, bluegill, black crappie, and yellow perch. Cancalosi concluded that no centrarchids occurred naturally in the Colorado reach of the basin. Several of the more habitat-sensitive species found slightly eastward a century ago by Hay (1887) and Cragin (1885) were absent from Cancalosi's collections. Springs on the North Fork Republican River still support a trout hatchery, near Wray, and a self-sustaining brown trout population locally (Metcalf 1966; Cancalosi 1981).

The Republican drainage in Nebraska had most of the species reported from Colorado and western Kansas, based on collections reported by Johnson (1942) and historical records compiled by Jones (1963). Streams in Dundy County were rich in numbers of species, partly because the drainage had developed spring-tributary and turbid-river habitats there (e.g., Rock Creek vs. Republican and Arikaree mainstems). Johnson (1942) reported 29 species from Dundy County alone, 24 of which were probably native. Johnson's collections preceded construction of major reservoirs in the basin, but smaller impoundments in the area had been stocked long before his surveys with largemouth bass, yellow perch, sunfish and "crappies" (species not indicated), black bullhead, channel catfish, rainbow trout, brook trout, brown trout, and common carp (Jones 1963). A hatchery producing trout and other fishes had long operated near Benkelman, Nebraska.

In 1972, Bliss and Schainost (1973a) collected fishes at 125 sites on 77 streams in the Republican basin in Nebraska, surveys more extensive than those by Johnson and other predecessors in the region. Several reservoirs (Bonny in Colorado, and Enders, Harry Strunk, Swanson, and Harlan County in Nebraska) and associated irrigation, using surface flow and ground water, were developed between Johnson's (1942) and Bliss and Schainost's investigations. Bliss and Schainost reported 37 species from the Republican drainage in Nebraska. Species found by them but not by Johnson included northern pike, smallmouth bass, gizzard shad, white bass, freshwater drum, emerald shiner, bigmouth shiner, longnose dace, longnose sucker, and plains topminnow. All of these species seem to be recent introductions, established since construction of the named reservoirs; the last four species probably entered as bait seined in the Platte drainage. Among native species reported by Johnson but not found by Bliss and Schainost are the speckled chub, sturgeon chub, silver chub, river shiner, and common shiner.

Smoky Hills Province

South of the Republican River, the lower reaches of the Saline, Solomon, and Smoky Hill rivers gained a few species, in their indigenous faunas, as their discharge increased because of confluence of tributaries and runoff as rainfall increased eastward in the basin. However, the Cretaceous formations exposed there provide few good aquifers, and many of the springs that do exist are saline. Tributaries that arise in the Smoky Hills province, west of the Flint Hills escarpments and east of fluvial sand-and-gravel deposits composing the Ogallala aquifer, have intermittent, turbid flows, and some are highly saline. An extreme example is Salt Creek, tributary to the Saline River in Russell County, Kansas, where chlorides increase from about 400 to more than 8,000 mg/L along its course and the number of

species declines from 14 to 1 (plains killifish). The marginally suitable habitats for fishes in the Smoky Hills province deteriorated with settlement and agricultural development, and stream-fish diversity in this reach declined rapidly (Metcalf 1966). Most large reservoirs are in this part of the basin, including Lovewell, Kirwin, Webster, Glen Elder, Wilson, Cedar Bluff, and Kanopolis (Fig. 4; Table 1). Construction of these lakes in the 1950's and 1960's radically changed local aquatic habitats and the amount and character of flows downstream. Several species were introduced into the impoundments, and others expanded their ranges westward because of altered flow regimes (Table 5). In 1983, Tomelleri et al. (1986) found as many species (27) as had previously been reported in Big Creek, an unimpounded stream that traverses this part of the basin and has a century-long record of collections; but American eel, hornyhead chub, redfin shiner, common shiner, Topeka shiner, and stonecat had been replaced by gizzard shad, golden shiner, white bass, black crappie, walleye, and freshwater drum.

In 1976, personnel of the Kansas Fish and Game Commission (now Kansas Department of Wildlife and Parks) analyzed fish populations in river basins that traverse the High Plains and Smoky Hills provinces, including stream reaches above and below reservoirs. The results, as reported by Kansas Department of Health and Environment (1978), were as follows: Saline River basin, 25 species found at 16 sites, average standing crop 168 kg/ha, range 11–893 kg/ha; Solomon River basin, 27 species at 36 sites, average standing crop 244 kg/ha, range 2–893 kg/ha; and Smoky Hill River basin, 32 species at 19 sites, average standing crop 280 kg/ha, range 6–893 kg/ha. Standing crops in the Smoky Hill River downstream from Kanopolis Reservoir (Fig. 4), including sites below the confluence of the Saline and Solomon with Smoky Hill, averaged 496 kg/ha, whereas standing crops upstream from Kanopolis dam (the major reach including Cedar Bluff Reservoir) averaged 182 kg/ha.

The Lower Basin

In the Flint Hills province, about 30 km downstream from the juncture of the Smoky Hill and Republican rivers, the Kansas River is joined by the Blue River, its principal remaining tributary (Fig. 2). The Little Blue and Big Blue rivers arise just south of the Platte River, which contributes much of their flow, owing to southward incline of the water table and subsurface flow through sand and gravel intervening between the Platte and Blue River headwaters (Minckley 1959). Below the confluence of the Little Blue and Big Blue rivers in northern Kansas, the Blue River flows southward into the Flint Hills, whose grass-covered slopes differ markedly from the extensively cultivated, loess and till-mantled plains in the northern part of the Blue River drainage.

About 50 species representing 13 families are native to the Blue River basin (Table 5). Minckley (1959) caught 45 of these in surveys in the Kansas part of the basin in 1957–58, as well as three introduced species: common carp, goldfish, and black crappie. Minckley did not find the following species, reported previously by other workers: American eel, blue sucker, highfin carpsucker, white bass, walleye, and yellow perch. No major reservoirs existed in the Blue River basin at that time, but Tuttle Creek Reservoir was impounded soon thereafter (Table 1). In 1973, Bliss and Schainost collected fishes at 337 sites in the Blue River drainage in Nebraska and found 27 species, all but the common carp being native. Bliss and Schainost (1973b, 1973c) did not find eight species that were reported in the same area by Meek (1895), Evermann and Cox (1896), or Johnson (1942): bigmouth buffalo, highfin carpsucker, shorthead redhorse, speckled chub, river shiner, Topeka shiner, bluntnose minnow, and johnny darter. The highfin carpsucker probably has been extirpated from the Blue River basin, and records of the river shiner by Evermann and Cox (1896) were referred instead to the sand shiner by Johnson (1942). Species found in Nebraska but not in Kansas are the bigmouth shiner, brassy minnow, and tadpole madtom, characteristic of small, cool, sandy, and low-gradient streams. Species present in the lower part of the basin but not in Nebraska are southern redbelly dace, rosyface shiner, redfin shiner, and common shiner, which are characteristic of clear, rocky streams with higher gradient, and goldeye, gizzard shad, buffalofishes, sauger, and freshwater drum, which are big-river fishes. Standing crops of fishes at five sites sampled in 1976 averaged 383 kg/ha (range 160–845 kg/ha; Kansas Department of Health and Environment 1978).

East of Blue River, about 28 species were indigenous to northern tributaries of the Kansas River, and 49 species inhabited its southern tributaries (Cross 1967). Most northern tributaries, draining the glaciated region, were turbid and

shallow with sandy substrates, whereas most southern tributaries were relatively clear and had strong riffle-pool development because they drain unglaciated limestone uplands. Some of the southern streams retain populations of species that were once more widespread in the basin than they are today: southern redbelly dace, hornyhead chub, rosyface shiner, redfin shiner, Topeka shiner, common shiner, slender madtom, longear sunfish, blackside darter, and johnny darter. Hartmann et al. (1980) reported standing crops of fishes that averaged 150 kg/ha at 13 sites in northern tributaries of Kansas River (Delaware River and Stranger Creek) in 1976. Excluding one site with 1,234 kg/ha, owing to a concentration of common carp and river carpsuckers, the average for these glaciated drainages was 61 kg/ha (range 8–140 kg/ha). Standing crops reported for 16 sites in the Wakarusa River, a southern tributary opposite the Delaware River and Stranger Creek, averaged 274 kg/ha. Excluding one site with an extreme value of 1,056 kg/ha, the average for the Wakarusa sites was 190 kg/ha (range 61–467 kg/ha). In 1972, diversity index values were determined by Huggins and Moss (1975) for fishes in a small northern tributary of the Kansas River affected by channel alterations where it crosses the river flood plain north of Lawrence, Kansas. Twenty-one species were found in 11.2 km of stream that Huggins and Moss divided into four nearly equal segments, three unchannelized and one channelized. Shannon index values in the unchannelized segments were 2.41, 2.51, and 2.70, and in the channelized segment, 1.39.

Fifty-five species of fish were indigenous to the Kansas River mainstem a century ago. All were tolerant of great fluctuation in discharge, shifting-sand substrate, and frequent high turbidity. Several species were peculiarly adapted to these conditions: shovelnose and pallid sturgeons, barbeled minnows of the genera *Platygobio* and *Macrhybopsis* (Moore 1950), plains minnow and western silvery minnow, and river carpsucker—benthic species dependent on tactile and chemical sensory systems. The habitat excluded sight-feeding predators, so the main piscivores were gars and catfishes. The mainstem habitat was inhospitable to species in upland streams, limiting their movement between northern and southern tributaries, partly accounting for past differences in their faunas. Because of recent changes in the mainstem habitat, the Kansas River is now a less effective barrier to fish dispersal, and several species once confined to its southern tributaries now inhabit its northern tributaries as well, reducing the distinctiveness of their faunas (Layher and Cross 1987).

Turbid-river species prevalent in the mainstem fauna persisted into the middle of this century, but were gradually replaced by planktivores and visual predators in the past three decades. These changes occurred as the system of reservoirs developed, ultimately regulating the flow of all major streams in the basin. The reservoirs stabilized flows downstream, reduced turbidity and sediment transport, increased plankton abundance, and enhanced benthos production where substrates were stable (Cross et al. 1982; Cross and Moss 1987; Tyus 1990). Gizzard shad and white bass probably did not occur in streams west of the Blue River because neither species appeared in reservoirs constructed on those streams until they were stocked, several years after impoundment in some cases (Cross 1967). Centrarchids other than green sunfish and orangespotted sunfish owe their present abundance in the basin to impoundments and regulated stream flow, and buffalofishes, drum, flathead catfish, and walleye either extended their ranges or became more common westward after the rivers were impounded. Human introductions and natural invasions (e.g., skipjack herring) affected the composition of the present fish community in the lower part of the basin, but the altered lotic habitats that permitted and sustained the changes are attributable to reservoirs built from 1948 to 1977 (Table 1).

Monitoring Programs of Various Agencies

The U.S. Geological Survey began sampling stream flow and water quality within the Kansas River system in 1894 in the Republican drainage (Boohar et al. 1991). Unfortunately, early sampling was inconsistent, and consequently, periods of records for sites were frequently disjunct. Seventy-four stations (12 water quality) in Kansas (Geiger et al. 1991), 54 stations (4 water quality) in Nebraska (Boohar et al. 1991), and 2 stations (0 water quality) in Colorado (Ugland et al. 1991) were sampled during 1990.

Additional water quality monitoring is conducted by the states. Kansas Department of Health and Environment began sampling bimonthly for selected heavy metals, chemicals, and

pesticides in 1967. Samples were collected from 41 stations during 1991. The longest period of record is 1967–92 (J. Fry, Kansas Department of Health and Environment, personal communication).

Nebraska maintains five ambient water quality projects and one special project within the Kansas River basin. Ambient stations are sampled monthly. The special project location is sampled weekly from April to September, and then collections are taken monthly. In addition, Enders Reservoir and one small impoundment (Big Indian Lake) are established lake water quality stations. Other lakes are sampled on a 3-year rotation. Lake samples are collected quarterly (D. Jensen, Nebraska Department of Environmental Control, personal communication).

Colorado Department of Health began water quality sampling at three stations in the drainage in 1968. All but one were discontinued by 1983. One station is maintained on the North Fork Republican River near the Colorado–Nebraska boundary. Heavy metals and water chemistry parameters are measured bimonthly (J. Farrow, Colorado Department of Health, personal communication).

Kansas and Nebraska participate in the Regional Ambient Fish Tissue Monitoring Program (RAFTMP; Cringan 1991; D. Jensen, personal communication). Fish tissue is screened annually to determine levels of pesticides, PCB's, and metals (Cringan 1991). Forty-four stations have been sampled in the Kansas River system in Kansas since 1982, with 8–15 sites completed annually (J. Fry, personal communication). About 60–70 fish tissue samples have been collected historically from the Republican and Blue River systems in Nebraska, with five stations assessed in 1991 (D. Jensen, personal communication). Colorado Department of Health had one RAFTMP station in the mid to late 1980's on the Republican River, but no current RAFTMP sites exist (J. Farrow, personal communication).

Twelve benthos stations are sampled once per year by Kansas Department of Health and Environment on a rotational basis through spring, summer, and fall within the system in Kansas (J. Fry, personal communication), whereas 18–21 stations are sampled annually for macroinvertebrates in the Republican and Blue River basins in Nebraska (D. Jensen, personal communication). Benthos are not sampled by Colorado Department of Health in the basin in Colorado (J. Farrow, personal communication).

Kansas Department of Wildlife and Parks, Nebraska Game and Parks Commission, and Colorado Division of Wildlife have standardized regimes for sampling lake fishery resources in the Kansas River basin (Zuerlein and Taylor 1985; Mosher and Willis 1987; C. Bennett, Colorado Division of Wildlife, personal communication). Electrofishing, seines, frame nets, and gill nets are used by all states to collect fishes. In addition, NGPC uses otter trawls to sample juvenile and small fishes. Normally, each type of gear is used annually if possible to secure a sample. Creel surveys are conducted periodically to assess harvest and use characteristics in Kansas River basin reservoirs.

Only Nebraska has a structured stream fishery sampling procedure. Eighteen to 21 stations located in the Kansas River system are sampled annually using electrofishing gear (D. Jensen, personal communication). Current Kansas Department of Wildlife and Parks activity in stream sampling is limited. Sampling occurs infrequently by biologists conducting field evaluations for agency comments relative to regulatory agency requests (e.g., U.S. Army Corps of Engineers, Kansas Division of Water Resources, and watershed districts). Gear utilized on small streams includes backpack electrofishers and an assortment of seines. Reservoir sampling gear is used for collections taken on large streams. Kansas Department of Wildlife and Parks recently organized a committee to write a stream sampling manual, which may stimulate stream sampling within Kansas. Annual fisheries monitoring within the drainage does not occur in Colorado (C. Bennett, personal communication).

Restoration

The Kansas River system has been altered greatly by humans, and realistically, it can never be truly natural again. A major change is establishment of thousands of impoundments that intercept runoff and regulate flows in a basin that had no permanent lentic habitat other than oxbows along some of its stream courses. Fish communities have changed accordingly; species adapted to lakes and tolerant of regulated flow have increased, whereas species adapted to unmodified lotic conditions have declined or disappeared. These fundamental changes are not likely to be reversed. However, the current system can be enhanced.

First, reliable biological data are needed to assess stream integrity. Nebraska has the most integrated monitoring procedure, in which water quality, macroinvertebrate, and fishery data are collected; Kansas needs to develop a stream fisheries monitoring system. Colorado should expand the number of water quality stations and establish fish and invertebrate collecting stations.

Second, many streams in the western basin have little or no flow because of irrigation and conservation practices. Because water has been overappropriated, states must shut down enough water rights holders to allow permanent flows where they existed historically. In addition, states should aggressively pursue water rights acquisition. Soil and water conservation practices, even future ones, probably cannot be eliminated. However, newly constructed or reconstructed ponds on historically permanent tributaries should have control features that allow maintenance of stream flow.

Third, bank stabilization structures in many situations could be eliminated if a sufficient riparian zone were maintained. Also, riparian zones are important filtering mechanisms and could enhance water quality (Welsch 1991). A solution is to require landowners to reestablish or maintain riparian corridors, or to provide necessary incentives so that this is accomplished. States should actively pursue conservation easements on these areas.

Fourth, physical alterations frequently are begun or completed without proper permits. Permitting agencies should refrain from merely granting after-the-fact permits. In addition, fines should be imposed to reflect environmental damages. Ideally, illegally altered reaches should be restored, and the costs should be borne by those responsible.

Finally, improved ag-chemical management is needed to control major nonpoint pollution sources. Education should be a major component in addressing this problem, as many individuals applying ag-chemicals are uninformed as to need for and proper application procedures and consequences of applications. Problem areas, identified by water quality monitoring, may require intensive management. Reduced application rates, restricted application methods, conservation practices, and banning of problem substances could be used in intensive management areas.

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Status of Selected Fishes in the Missouri River in Nebraska With Recommendations for Their Recovery

by

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Abstract. Population density of five species of chubs and two species of minnows in the Missouri River in Nebraska has been reduced by as much as 95% since 1971. Burbot have been nearly extirpated, sauger have been greatly reduced, and blue catfish are rare. Reasons for the decline of these species include removal of snags from the river; cessation of organic matter and sediment transport because of the construction of large dams on the mainstem and tributaries; cutoff of floodplain connection through channelization, degradation, and the cessation of flooding; alteration of the natural hydrograph to meet the need for commercial navigation; and reduction of the natural water temperature regime because of deep release of cold water from the large reservoirs. We propose remedial actions for each of these ecological changes, and we propose listing of several species as endangered in Nebraska.

In 1838, federal engineers initiated the most significant restructuring of the Missouri River since the last Pleistocene glacier retreated northward. Snags were removed, dams were constructed on the mainstem and tributaries, channels were armored with rock and piling, the natural hydrograph was replaced with a monthly metered flow, sediment and organic matter transport was short-stopped, and the floodplain was made safe for human development.

At the time of construction, nothing was done to mitigate damage to the ecosystem. The impact set in motion by these changes will never be thoroughly quantified, and a semblance of physical and biological equilibria will not happen again for decades, if ever (Petts 1984). We do know that the Missouri

River was shortened by at least 204 km and more than 178 million ha of river channel, erosion zone, floodplain grass and timber, and tributary valley lands were either inundated or converted to crop land (Hesse 1987; Hesse and Schmulbach 1991).

At least 160 species of wildlife were resident or migrant visitors to this ecosystem, and 156 native fish species lived in the mainstem and tributaries (Hesse et al. 1988; Hesse et al. 1989). Nebraska's imperiled Missouri River wildlife include the interior least tern (*Sterna antillarum*), piping plover (*Charadrius melodus*), peregrine falcon (*Falco peregrinus*), and bald eagle (*Hatiaeetus leucocephalus*), all protected by the Endangered Species Act (ESA). The pallid sturgeon (*Scaphirhynchus albus*) was most recently (1990) listed as endangered (Federal Register 55 (173):36641). Other species have been federally listed as Category 2 (taxa for which present information indicates the possible need to list, but more information is required before listing can proceed), including: blue sucker (*Cycleptus elongatus*), sturgeon chub (*Macrhybopsis gelida*), sicklefin chub (*Macrhybopsis meeki*), and lake sturgeon (*Acipenser fluvescens*). Paddlefish (*Polyodon spathula*) is a Category 2 species and was recently proposed for listing in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; Federal Register 56 (142):33894).

This paper discusses (1) differences in density of selected fish species over time and between reaches of the Missouri River, based on changing harvest by sport and commercial fishermen and on catch per unit effort (CPUE) from biological surveys, and (2) remedial actions that will preserve and restore original features and functions of the Missouri River as an ecosystem.

Sources of Data and Methods

The Nebraska Game and Parks Commission has supported research on Missouri River fisheries since the late 1950's. Historical databases exist from seining, explosives, creel surveys, commercial fishing reports, electrofishing, gill netting, and plankton drift netting.

Many other methods were used to collect in unique situations. These methods are discussed in Mestl and Hesse (1991). Seine samples are reported as the number of fish per seine haul. One standard seine haul constituted a perpendicular extension of a 15.24- × 1.83-m bag seine, followed by an extended drag to shore while maintaining one end of the net stationary. However, standardizing a seine haul was very difficult because of varying depth and the condition of the substrate. Mesh size was always 6.13 mm. All seined fish were preserved and identified in the laboratory. Cyprinids and catfish were collected from tributary streams with an explosive (primacord). A unit of effort consisted of a 15.2-m length of explosive, containing 162.5 grains of PETN/m. Bankline and sandbar habitats were sampled. A block net was used to capture fish killed by the blast. Angler surveys have been conducted periodically in the tailwater of Gavins Point Dam and at selected locations downriver since 1956. The most recent survey was a recreational use survey conducted during 1992.

Commercial fishers were first required to purchase a license and report their catch beginning in 1944 (Nebraska) and 1945 (Missouri). Although reports were required, they were completed annually, and by fishers themselves, with little opportunity for verification. However, we believe these reports are useful to show trends in abundance of selected species based on harvest trends.

Boat-mounted electrofishing (AC and DC) has been used since the early 1960's to collect a wide range of species. We have observed different catch rates associated with the widely varying water quality conditions throughout the river. For this reason only catch per unit effort (CPUE) that differed widely is reported. Small differences cannot be justifiably assigned to changing conditions of habitat and water management. Collections were based on time spent sampling, and CPUE was the number of fish per unit of time spent electrofishing.

Experimental gillnet collections were usually limited to the unchannelized Missouri River between Fort Randall Dam and Lewis and Clark Lake (Gavins Point Dam; Figure). This is the only reach in Nebraska with extensive off-channel and sandbar pool habitat remaining. The nets were either 91 m or 61 m long, and 2.44 m deep, with six equal length panels of netting ranging from 12.7-mm to 76.2-mm mesh sizes. Nets were anchored late in the afternoon and retrieved early the next day. Data were recorded by net length, and CPUE was the number of fish caught per net-night.

Larval fish were filtered from the main channel at cutting and filling banks and at mid-channel with paired, 1-m-diameter plankton nets (560 microns). Flow meters in the net mouths were used to quantify volume of water filtered, and duration per tow was minimal to prevent net clogging. The

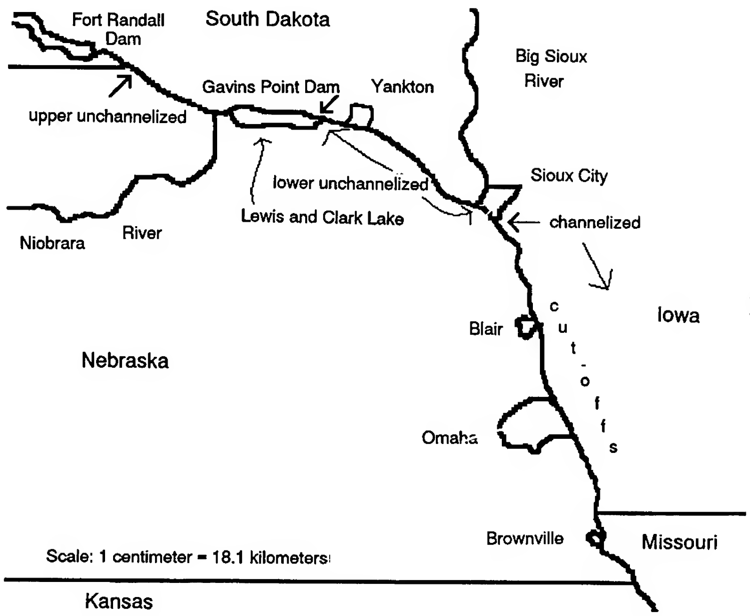

Figure. Map of the Missouri River showing the lowermost dams and unchannelized and channelized segments.

CPUE was reported as the number of larvae per 1,000 m^3 of water strained. Larval fish were identified to species, except that cyprinids and most suckers were grouped by family (Auer 1982). Larval blue sucker however, were identified to species (Hogue et al. 1981).

Status of Selected Fishes

River Chubs in the Missouri River

Five species of chubs were common in the Missouri River before it was channelized and impounded, including sturgeon chubs, *sicklefin chubs*, flathead chubs *(Platygobio gracilis)*, silver chubs (*Macrhybopsis storeriana*), and speckled chubs (*M. aestivalis*).

Sturgeon chubs were found in the Platte River at Grand Island, and in Bazile Creek near Niobrara (Everman and Cox 1896). Johnson (1942) collected them throughout the Platte, Republican, Elkhorn, and Missouri rivers. Sicklefin chubs were collected by Meek (1892) and Johnson (1942) from the Missouri River and by Morris (1960) from the Platte River. Flathead chubs were found extensively throughout most of Nebraska's rivers (Jones 1963). They were reported from all drainages except the Big Blue and Little Blue river systems (Johnson 1942). Silver chubs were distributed throughout the Missouri, Plate, Elkhorn, Loup, and Republican rivers (Everman and Cox 1896; Johnson 1942; Harlan and Speaker 1956; Morris 1960). Johnson (1942) found speckled chubs in the Platte, Elkhorn, Loup, and Republican rivers, and Meek (1894) collected them in the Big Blue River. Cross (1967) reported sturgeon chubs as widely distributed in the Missouri and Kansas rivers; sicklefin chubs were found in the Missouri and Mississippi rivers downstream from the Missouri River confluence, flathead chubs were primarily restricted to the Missouri, silver chubs were common only in the Missouri and Kansas rivers, and speckled chubs were common in the shallow side channels of the Missouri. Bailey and Allum (1962) reported sturgeon chubs from the Missouri and its largest western tributaries—the White, Cheyenne, and Grand rivers. Sicklefin chubs do not ascend the Mississippi beyond the confluence with the Missouri, and they reported its upstream limit in the Missouri River as the mouth of the Little Missouri River in North Dakota. Flathead chubs were reported to be the dominant minnow in the turbid Missouri and its larger western tributaries in South Dakota.

Silver chubs were known only in the Missouri River into southeastern South Dakota, and speckled chubs were not known to occur north of Nebraska. Pflieger (1975) considered speckled chubs common in the Missouri and lower Mississippi rivers. Sturgeon chubs, sicklefin chubs, flathead chubs, and silver chubs were considered common inhabitants of the Missouri River and the Mississippi River downstream from the Missouri confluence (Pflieger 1975). However, Pflieger and Grace (1987) reported a dramatic decline in the abundance of flathead chubs from 1940 to 1983 throughout the Missouri River in Missouri. Although they reported slight increases in the density of sturgeon chubs, sicklefin chubs, silver chubs, and speckled chubs in Missouri, these species were only numerous in the lowermost sections of the Missouri River nearest to the Mississippi River. Upper stations on the Missouri River in Missouri and adjacent to Nebraska showed low numbers of these chubs in 1978–83 collections (Pflieger and Grace 1987).

During 1971, 1974, and 1975, 16,384 small fish were seined during 3,060 seine hauls with a 15-m bag seine (6.13-mm mesh) from the channelized Missouri River in east-central and southeast Nebraska (Hesse and Wallace 1976). No sturgeon chubs or sicklefin chubs were collected; 324 (2.0% by composition) flathead chubs, 1,195 (7.3%) silver chubs, and 72 (0.4%) speckled chubs were collected (Table 1). From 1986 to 1990, 6,217 small fish were seined (234 seine hauls, 15-m bag seine, 6.13-mm mesh) from the channelized Missouri River in east-central and southeast Nebraska. One sicklefin chub and 1 sturgeon chub (0.03%), 3 (0.05%) flathead chubs, 120 (1.9%) silver chubs, and 2 (0.03%) speckled chubs were collected. Mean catches per seine haul were as follows: flathead chubs, 0.11 (1971–75) and 0.01 (1986–91); silver chubs, 0.39 (1971–75) and 0.51 (1986–91); speckled chubs, 0.02 (1971–75) and 0.009 (1986–91). Seine hauls were difficult to replicate; percent composition is a better indicator of population trend than CPUE in this instance.

Two reaches (165 km) of the Missouri River in northeast Nebraska remain unchannelized, although the uppermost reach (72 km) is isolated between Fort Randall and Gavins Point dams. During 1983–90, 32,448 small fish were seined (1,360 hauls, 15-m bag seine, 6.13-mm mesh). No sturgeon chubs, sicklefin chubs, or speckled chubs were collected; one (0.003%, 0.0007/haul) flathead chub, and seven (0.02%, 0.005/haul) silver chubs were collected.

River Minnows in the Missouri River

Plains minnows (*Hybognathus placitus*) and the western silvery minnows (*H. argyritis*) were common in the Missouri River at the turn of the century. They are similar species taxonomically and with respect to habitat preferences (Pflieger 1975). Jones (1963) reported they were widely distributed in the Platte, Republican, Loup, Elkhorn, and Niobrara rivers. The plains minnow was the most abundant minnow in the upper Missouri River in

Table 1. The relative abundance and catch per unit of effort (CPUE) of flathead chubs, silver chubs, speckled chubs, plains and silvery minnows combined, and total cyprinids seined from the Missouri River, Nebraska.

Species	Location	Period	Effort	No. sampled	Sample size	%	CPUE
Flathead chubs	channelized	1971–75	3,060	324	16,384	2.0	0.11
	channelized	1986–90	234	3	6,217	0.05	0.01
	unchannelized	1983–90	1,360	1	32,448	0.003	0.0007
Silver chubs	channelized	1971–75	3,060	1,195	16,384	7.3	0.39
	channelized	1986–90	234	120	6,217	1.9	0.51
	unchannelized	1983–90	1,360	7	32,448	0.02	0.005
Speckled chubs	channelized	1971–75	3,060	72	16,384	0.4	0.02
	channelized	1986–90	234	2	6,217	0.03	0.009
	unchannelized	1983–90	1,360	0	32,448	0.0	0.0
Plains and silvery minnows	channelized	1971–75	3,060	4,589	16,384	28.0	1.5
	channelized	1986–90	234	102	6,217	1.6	0.4
	unchannelized	1983–90	1,360	21	32,448	0.06	0.01
Total cyprinids	channelized	1971–75	3,060	6,180	16,384	37.7	2.01
	channelized	1986–90	234	229	6,217	3.7	0.9
	unchannelized	1983–90	1,360	28	32,448	0.09	0.02

Missouri, declining as one proceeded downriver (Pflieger 1975). It occurred in schools in association with western silvery minnows, silver chubs, and flathead chubs (Pflieger 1975).

Plains minnows were abundant in the shallow, organic backwaters of the Missouri River (Cross 1967), and were abundant in the most turbid of the northern plains streams, including the Missouri River (Bailey and Allum 1962). Pflieger and Grace (1987) reported that western silvery minnows, plains minnows, and chubs composed 95.4% of all small fish in 1940–45, with plains minnows and flathead chubs by far the most numerous. They also reported a decline in the abundance of plains minnows and western silvery minnows from 1940 to 1983.

During 1971–75, 4,589 plains minnows and silvery minnows were seined from the channelized Missouri in eastern Nebraska, among 16,384 small fish (Hesse and Wallace 1976). They represented 28% of all small fish and ranked first in percent composition (Table 1). By 1986–90 only 102 (1.6%) were collected among 6,217 small fish seined in the same reach. Most plains minnows and silvery minnows, during 1971–74, were collected in southeast Nebraska stations on the Missouri River, where they represented an average of 38% of nearly 12,000 small fish collected (Hesse and Wallace 1976). During 1986–90 they were just 11.4% of all small fish captured at the same locations.

Missouri River Chubs and Minnows in Other Nebraska Streams

The Nebraska Department of Environmental Quality collected over 70,000 small fish in 350 stream sites across Nebraska (excluding the Missouri River) during 1984–88 (Bazata 1991). Flathead chubs (396 specimens) composed only 0.6% by composition and were collected in only 8.8% of the streams sampled. Johnson (1942) reported that this species was found in all drainages in Nebraska except the Big Blue and Little Blue rivers. Peters et al. (1989) collected them in only 4% of 874 electrofishing grids in the lower Platte River.

The Nebraska Department of Environmental Quality did not collect sturgeon chubs or sicklefin chubs anywhere in Nebraska streams, and Peters et al. (1989) collected one sturgeon chub and no sicklefin chubs from the lower Platte River. The Nebraska Department of Environmental Quality collected 4 (0.006% composition, 0.6% of streams) silver chubs, 12 (0.02% composition, 0.9% of streams) speckled chubs, 208 (0.3% composition, 2% of streams) plains minnows, and 182 (0.3% composition, 5.4% of streams) western silvery minnows (Bazata 1991). Peters et al. (1989) collected only 8 silver chubs (0.9% of 874 grids), 28 speckled chubs (3% of 874 grids), 473 plains minnows (9% of 874 grids), and 180 western silvery minnows (3% of 874 grids) from the lower Platte River.

The lower Niobrara River was sampled with primacord in 1976–78 (Hesse et al. 1979; Newcomb et al. 1981); 3,083 (15.3% composition) flathead chubs, 20 (0.1% composition) silver chubs, and 40 (0.2%) plains minnows were collected. This survey was repeated in 1991; 104 (12.5% composition) flathead chubs and no silver chubs or plains minnows were collected. Catch rate may be a better indicator of population density with an explosive because the explosive effort was easily duplicated, and fish response to primacord is independent of other factors (e.g., water quality). Flathead chubs were collected at the rate of 31 fish per blast in 1976–78 but only 5 fish per blast in 1991.

On the basis of these data we recommend that sturgeon chubs, sicklefin chubs, flathead chubs, silver chubs, speckled chubs, plains minnows, and western silvery minnows be listed as endangered in Nebraska.

Burbot

Bailey and Allum (1962) reported that burbot (*Lota lota*) were found east of the Black Hills in the Cheyenne River system and were common in the Missouri River in South Dakota. Johnson (1942) collected one from the Niobrara River in Nebraska and reported them in the Platte River; however, he suggested their range was restricted to the Missouri River and lower ends of large tributaries. Burbot were rare in Missouri's portion of the Missouri River (Pflieger 1975). Cross (1967) considered burbot primarily residents of the Missouri River mainstem; however, records exist of burbot collected from the Kansas River.

Burbot were commonly harvested by sport fishers in the tailwater of Gavins Point Dam for several years after it was closed in July 1955. Orr (1958, 1962) reported 510 (5.1% composition) burbot caught there in 1956, 4,780 (2%) in 1958, 0 in 1961 (out of an estimated harvest of 539,945), and 0 in 1962 (out of 710,389; Table 2). Commercial fishers harvested 1,500 kg of burbot from Lake Sakakawea (Garrison Dam on the mainstem Missouri River in North Dakota) in 1960, none from 1961 to 1974,

Table 2. Sport fishing harvest of burbot and sauger from the Missouri River in the Gavins Point Dam tailwater, 1956–92.

Year	All harvest	Rate	Burbot		Sauger	
			No. caught	%	No. caught	%
1956	10,000	1.6	510	5.1	2,700	27.0
1958	239,000	1.6	4,780	2.0	71,700	30.0
1961	539,000	1.4	0	0.0	264,110	49.0
1962	710,000	1.4	0	0.0	284,156	40.0
1972	18,441	0.4	0	0.0	830	4.5
1978	29,294	0.1	0	0.0	3,808	13.0
1984	45,101	0.6	0	0.0	4,143	9.0
1992	51,523	0.5	0	0.0	106	0.2

11 kg in 1975, and none through 1984 (unpublished report, North Dakota Game and Fish Department, Bismarck).

Sport fishers in the area between the Gavins Point Dam tailwater and Rulo, Nebraska, were surveyed during 1972 (Groen 1973). Burbot were not harvested in the tailwater of Gavins Point Dam or from the unchannelized reach downstream. However, six burbot (1% by composition) were harvested by sport fishers downstream from Omaha. User surveys conducted in 1978, 1984, and 1992 did not report any burbot as harvested or caught and released.

Electrofishing in the channelized Missouri River in eastern Nebraska (1971–75) captured 13 burbot among 29,493 large fish (0.04%; Hesse and Wallace 1976). Since 1983, we have electrofished 2,019 large fish from these same locations and have not collected burbot. In addition, we have collected 7,024 large fish with electrofishing in the unchannelized sections in northeast Nebraska, including only 4 (0.06%) burbot.

Burbot still reproduce in northeast Nebraska portions of the Missouri River. Two larval burbot were collected in 1984 in the tailwater of Gavins Point Dam, three in 1985 (two in the tailwater and one upstream at Niobrara), and one in 1986 (16 km downstream from Gavins Point Dam). These six larvae were very rare among more than 150,000 fish larvae collected from nearly 400,000 m^3 of water. We recommend that burbot be listed as endangered in Nebraska.

Sauger

Sauger (*Stizostedion canadense*) were common in Nebraska, occurring in the Platte River west to the Nebraska–Wyoming border (Meek 1894; Everman and Cox 1896; Wyoming Game and Fish Commission 1940). Jones (1963) cited an 1896 Nebraska Fish Commission report that sauger were caught in large numbers from the Platte, Blue, Loup, Elkhorn, and Niobrara rivers; however, they were most abundant in the Missouri River. Pflieger (1975) stated that sauger are often associated with strong current and high turbidity and are somewhat restricted to large, free-flowing rivers. Sauger were common in the Missouri River in Kansas and a seasonal resident of the Kansas River (Cross 1967). Sauger were common in the Missouri River in South Dakota and in the lower ends of some larger tributaries (Bailey and Allum 1962).

Large sport fisheries for sauger developed in the tailwaters of the large mainstem dams as they were constructed (Bailey and Allum 1962). Between July 1959 and March 1960, 31,291 sauger were harvested from the tailwater of Oahe Dam (Bailey and Allum 1962). Gavins Point Dam was closed in July 1955; the sport harvest gradually increased to 239,976 fish (1.6/h) by 1958 in the tailwaters, and 30% (71,993) were sauger; Orr 1962; Table 2). The sport harvest peaked in 1962 at 710,389 fish (1.4/h), and sauger represented 40% (284,156) of the catch (Orr 1962). By 1972, harvest in the tailwater decreased to 18,441 fish, and only 830 sauger were caught (Groen 1973). In 1992, tailwater anglers harvested 51,523 fish, and only 106 sauger were caught (Hesse et al. 1992).

Few records exist of sport fishing in the riverine reaches, but those that do paint a picture of extraordinary fishing opportunities. Robinson (1958b) surveyed ice fishers using the Decatur cut-off during the winter of 1958–59; 209 fishers averaged 1.7 fish/h; 64.3% of their catch was sauger, 23.9% was crappie, and 11.7% was largemouth bass. Comments by fishers included the following: "ice fishing

Table 3. Alternating current electrofishing catch of sauger from the Missouri River, Nebraska, 1964, 1975, and 1990.

Year	Channelized, % of all fish	Channelized, sauger/h	Unchannelized, sauger/h
1964	10.0	10.0	11.0
1975	3.0	3.3	
1990	0.3	0.5	1.6

has been good this year but last winter was much better with a larger take of sauger."

Channelization of the river south of Omaha began in the late 1930's, but not until the late 1950's, north of Omaha. Scientific surveys were first implemented as channelization commenced in the 1950's, and Robinson (1958a) noted a "marked difference in the composition of electrofishing catches" north of Omaha, although he did not elaborate on the southern catch. However, main channel catches during 27.5 h of electrofishing (north of Omaha), included 138 (7%) sauger, 119 (6%) largemouth bass, and 148 (7.5%) crappie. Morris (1965) captured 10 sauger/h of electrofishing (10% composition) near Blair (north of Omaha; Table 3). During 1971–75, 16,418 fish were electrofished near Blair; 450 (2.7%) sauger were collected, and the catch rate had dropped to 3.3/h of electrofishing (Hesse and Wallace 1976). During 1986–90 we electrofished 8.5 h at Blair, and collected 500 fish; none was sauger. We electrofished 40 additional hours during this same period at six other sites in the channelized section and collected 2,214 fish; 13 (0.6%) were sauger (0.3/h).

In 1964, Morris (1965) averaged 11 sauger/h with a boatshocker in the unchannelized Missouri River near Yankton, South Dakota (downstream from Gavins Point Dam; Table 3). Between 1983 and 1990 we electrofished 48.7 h at St. Helena (Cedar County), which is about 8 km from Morris's collection site. We collected 1,681 fish; 80 (4.8%) were sauger, and the catch rate was 1.6/h. However, only five sauger were collected at St. Helena after 1984 (53 in 1983, 22 in 1984). Four other sites on the unchannelized reaches upstream and downstream from Gavins Point Dam and Lewis and Clark Lake were electrofished between 1983 and 1990; 221 sauger (6.4%) were among 3,455 captured fish, and the catch rate was 1.9/h.

Experimental gill nets have been used to collect fish in remnant backwaters of the Missouri River since 1983. These areas are rare and exist mostly in the unchannelized reach upstream from Lewis and Clark Lake. The sauger catch rate has declined steadily from 4.5/gillnet-night in 1983 to 0.3/gillnet-night in 1991 (Table 4). Sauger, as a percent of total fish composition, also steadily declined from 19.4% in 1983 to 4.4% in 1991. The mean CPUE for a year was compared with the following year in a *t*-test, and the annual decrease in CPUE was shown to be significantly different ($P = 0.05$).

Collection of larval fish also provided some insight into the decline of sauger in the Missouri River. We have collected more than 112,000 larval fish since 1983 (not including a large number from the Gavins Point Dam tailwater), and larval sauger density varied from 0.1 to 2.2/1,000 m^3 (mean = 0.9) in the reach upstream from Lewis and Clark Lake. Nelson (1968) reported that larval sauger density in 1965 was 10.6/1,000 m^3 in this same reach. Mean larval sauger density in the channelized section for 1986–91 was 1.1/1,000 m^3. Some or most of these may have drifted from the unchannelized section downstream from Gavins Point Dam, where mean larval sauger density was 2.3 for 1983–91. Sauger larvae composed 1.8% of all

Table 4. Experimental gillnet catch of sauger from the unchannelized Missouri River, Nebraska, during 1983–91.

Year	Total fish captured	Total CPUE	Total sauger	Sauger %	Sauger CPUE
1983	396	6.8	77	19.4	4.5
1984	393	6.7	59	15.0	3.3
1985	558	7.3	81	14.5	2.8
1986	280	7.4	20	7.1	2.0
1987	27	3.5	3	11.1	0.8
1988	501	3.8	5	1.0	0.2
1989	38	8.5	0	0.0	0.0
1990	164	5.8	0	0.0	0.0
1991	138	3.2	6	4.4	0.3

larvae in the unchannelized reach upstream from Lewis and Clark Lake, 0.7% in the lower channelized reach, and 0.2 % in the channelized reach.

Spawning sauger were collected from a glacial till outcropping in Boyd County, Nebraska, on the Missouri River at a maximum rate of 36/h of electrofishing during 1963–65 (Nelson 1968). We have duplicated his effort (similar equipment, time of year, time of day) periodically between 1982 and 1989. Average peak catch for the period was 3.7 sauger/h. We recommend that sauger be listed as endangered in Nebraska.

Blue Catfish

Blue catfish (*Ictalurus furcatus*) were known to colonize the Missouri River north to Montana; however, Pflieger (1975) reported that they also moved seasonally in response to water temperature, returning to the most southern reaches of their range, where water remained the warmest. Large dams on the Missouri and Mississippi rivers and their tributaries prevented this migrational response to environmental stimuli and probably contributed to their demise.

Churchill and Over (1933) suggested that blue catfish were widely distributed in the Missouri, White, James, Big Sioux, and Cheyenne rivers in South Dakota. However, by the early 1960's intensive netting and creel surveys resulted in only one small specimen collected downstream from Fort Randall Dam (Bailey and Allum 1962). Jones (1963) reported that its range was probably restricted to the Missouri River in Nebraska, with an occasional large specimen occurring in the Platte River as far west as Saunders County. The blue catfish was fairly common in the Missouri River and rare in the lower Kansas and Marais des Cygnes rivers of Kansas (Cross 1967). However, he noted the incredible size of the species. He cited frequent accounts of blue catfish exceeding 50 kg. We found a news article in the *Yankton Dakotian* dated 5 August 1862 that said, "Katphish, of fabulous dimensions, are being taken from the placid waters of the Big Muddy about these times. A great many of them weigh two and three hundred pounds."

Recently blue catfish have been caught only rarely by anglers in Nebraska's portion of the Missouri River. One weighing 45 kg was caught in Lewis and Clark Lake in August 1990. Smaller specimens are commonly channel catfish mistaken for blue catfish; few contemporary sport catches have been verified to be blue catfish.

Snow (1875) considered the blue catfish "the most valuable species in the river (Kansas River), since it is quite abundant" (Cross 1967). Kingsbury (1915) reported that "the catfish was an important factor in the settlement of Dakota, and in the opinion of many of the early settlers, the food problem would have been a very serious one had it not been for the abundant supply of this best of all fishes right at the threshold of the settlements." Audubon noted in 1858 that the catfish was a very valuable article of food in the Missouri River. For scores of years the early traders subsisted almost exclusively on buffalo (bison [*Bison bison*]) and catfish (Hesse and Mestl 1989).

Funk and Robinson (1974) reported that catfish composed 30% of the commercial catch in 1894. As a group they were heavily exploited at the turn of the century, especially large blue catfish. Between 1949 and 1971 the reported commercial harvest of blue catfish in Missouri's section of the Missouri River remained somewhat stable as a percentage of total catfish catch (16%). However, their total numbers in the catch declined by nearly 80% (Funk and Robinson 1974). Reported blue catfish commercial catch in Missouri increased from 4,292 kg in 1970 to 8,610 kg in 1985, whereas no blue catfish were harvested in Nebraska's portion after 1966 (Zuerlein 1988). Commercial blue catfish harvest in Nebraska declined steadily from 5,846 kg in 1944 to 654 kg in 1966 (Zuerlein 1988; Table 5).

Nebraska biologists have collected catfish from the Missouri River since at least 1958. The samples taken included many age classes, including young-of-the-year. Methods of capture included seine, gill net, trammel net, hoop net, rotenone, explosives, boat electrofishing, deepwater electrofishing, telephone generator, and the newest in electronic devices, euphemistically called the skoal box. We have gathered much of these data

Table 5. Mean annual reported harvest (kg) of catfish from the Missouri River in Nebraska during four time periods (Zuerlein 1988).

Time period	Blue catfish	Channel catfish	Flathead catfish
1944–53	4,383	12,101	9,074
1954–63	2,138	11,787	6,876
1964–73	1,704	9,004	3,251
1974–83	closed	7,541	5,116

and have only begun to analyze more than 50,500 individual records. Before 1991 only one blue catfish had been collected. However, in 1991, 15 young-of-the-year blue catfish were captured in total from three locations along the Missouri River in Nebraska south of Omaha. In Missouri's section, 63,191 catfish were sampled between 1980 and 1992; 1,350 (2%) were blue catfish. However, Missouri commercial fishers reported taking 37,983 kg of blue catfish, which is 27% of all catfish harvested during 1991 from the Missouri River in Missouri. We recommend that blue catfish be listed as endangered in Nebraska.

Other Species of Special Concern

Other species of special concern in Nebraska include lake sturgeon, which has probably been extirpated from Nebraska as a wild population; pallid sturgeon, which has been listed as a nationally endangered species and is very rare in Nebraska; shovelnose sturgeon (*Scaphirhynchus platorynchus*), which is declining throughout Nebraska's portion of the Missouri River; paddlefish, which is stable to declining in Nebraska (Hesse and Mestl 1992); longnose gar (*Lepisosteus osseus*), which is declining and becoming uncommon in Nebraska; shortnose gar (*L. platostomus*), which seems stable, but whose primary habitats have been eliminated; blue sucker, which seems to be stable in Nebraska, but is reduced throughout its range nationwide and is a candidate for national listing; and flathead catfish (*Pylodictis olivaris*), which has been reduced to fewer than 1,000 individuals in the unchannelized Missouri River upstream from Lewis and Clark Lake (Hesse and Mestl 1991).

In the following discussion we outline the reasons for the decline of these native fish species, and recommend remedial actions.

Discussion of Cause and Effect Factors

Snag Removal

Bilby and Ward (1991) reviewed available literature on the role played by large woody debris in stream ecology. Snags were reported to alter channel morphology by influencing sediment routing, thus creating pools, gravel bars, and depositional sites. These, in turn, reduced the rate of downstream transport of particulate material. Bilby and Likens (1980) suggested that a large part of stream organic matter is associated with woody debris.

Benke et al. (1985) determined that invertebrate diversity, standing stock biomass, and production per unit of surface area were much higher on snag habitat in the Satilla River, Georgia, than in the other two main habitats (shifting sandbars of the main channel and muddy depositional areas of backwaters). They reported that snag habitat contained 60% of total invertebrate biomass per unit length of river, even though snags composed only 4% of available habitat. The Satilla was heavily snagged in the 1940's.

Steam-powered snag boats began removal of snags from the Missouri River in 1838, when 2,245 large trees were removed from the river channel and 1,700 overhanging trees were cut from the bank in the first 620 km of river upstream from St. Louis, Missouri (Chittenden 1962). Before 1885, however, snag removal was somewhat random and extended only a few hundred kilometers up the Missouri River, although the number and tonnage of snags removed were immense (Suter 1877). After 1885, snagging intensified and became systematic. In 1901, snag boats removed 17,676 snags, 69 drift piles, and 6,073 overhanging trees in 866 km of river (Funk and Robinson 1974). Today, even unchannelized sections have few remaining snags.

Leaf abscission in fall contributed a pulse of organic matter to the river system, but leaves are 90% decomposed within 1 year (Risser et al. 1981). Conversely, large woody debris provided long-term supplies of organic matter, requiring 75 years for 95% decomposition in some instances (Melillo et al. 1983).

Trees of all types and sizes were essential as aquatic insect substrate, and they provided localized zones of reduced velocity for fish. Snags reduced mean stream velocity, increased the stream top width, provided long-term organic matter supplies, and aided in fine organic matter retention (Benke et al. 1985; Hesse et al. 1988).

Snag removal from the Missouri River was completed nearly 40 years ago, but dam construction eliminated large floods, and human encroachment on the floodplain stabilized the banks even along the unchannelized remnants. Few new snags have been introduced since 1954, when Gavins Point Dam was closed. In 1963, 68.9% of secondary production in the unchannelized reach in Nebraska was from snag habitat, while mud

substrate, backwater insect production contributed 19.3%, and sand substrate production was 11.8%. By 1980, snag production dropped to 50.4% of total production, while backwater production contributed 14.8% and main channel sand bar 35.8% (Mestl and Hesse 1992). Based on total available habitat, snag insect production in one unchannelized reach (downstream from Gavins Point Dam) was down by 65% between 1963 and 1980 (Mestl and Hesse 1992). Recent observations in the unchannelized reach upstream from Gavins Point Dam indicate that the insect community is even less abundant than in the downstream reach. We have not quantified production differences; however, we did quantify the amount of insect biomass drifting through both unchannelized sections in 1984 (Hesse and Mestl 1985). Mean monthly invertebrate drift biomass was 83 kg in the upper unchannelized section and 376 kg in the lower unchannelized section, nearly 4.5 times greater.

The changing relative abundance of fish in the Missouri River can most likely be explained by the changing availability of insects. For instance, flathead chubs used mostly terrestrial insects, which fall into the river from woody debris protruding from the water or along the bank, while plains minnows used the film of diatoms and insects from accumulating soft sediments in quiet backwaters (Cross 1967). Overhanging trees and snag production, and off-channel backwater production have been reduced so much that midchannel sandbar production has become a larger proportion of total system production. Flathead chubs and plains minnows have been replaced by emerald shiners (*Notropis atherinoides*), which feed primarily on zooplankton in higher-current sand substrates; insects are of secondary importance in their diet (Fuchs 1967). Sauger do not compete well with sight-feeding predators such as northern pike (*Esox lucius*) and smallmouth bass (*Micropterus dolomieu*) foraging for emerald shiners in shallow, nonturbid bars and backwaters.

We propose that large woody debris, brush, leaves, and grass should be returned to the Missouri River in large quantities. Such materials are available in communities near the river, and new legislation has banned yard waste from landfills in Nebraska beginning in 1994. Communities are exploring innovative environmental options for disposal of yard waste, and placing it in the Missouri River is a better way to use it than to bury it in overflowing landfills.

Loss of Floodplain Connectivity

The Missouri River had a wide (32 km) floodplain, part of which was inundated each year. Welcomme (1985) found a direct relation between duration of floodplain inundation and standing stock of fish the next year. Karr and Schlosser (1978) suggested that standing stock may decline by as much as 98% when the lateral linkage between floodplain and channel is severed. Junk et al. (1989) proposed the flood pulse theory as a mechanism to maintain the essential linkage between river channels and the floodplain.

The Missouri River has been deprived of a floodplain. More than 178 million ha of this essential habitat has been lost (Hesse and Schmulbach 1991). This habitat represented the off-channel area, where velocity was reduced and the bottom was muddy. Morris et al. (1968) determined that, as channelization occurred, 67% of the benthic insect production was lost in direct proportion to lost off-channel habitat.

We recommend that federal mitigation projects be expanded to include the entire length of the remaining riverine sections. Project design should include the hydraulic reconnection of old cut-off sections of the erosion zone to the main river. Through acquisition in fee title or environmental easement, a publicly owned corridor should be created to provide at least a minimal floodplain.

More than $100 million has been spent to build nearly 467 km of federal levees on both sides of the Missouri River from Sioux City, Iowa, to the mouth (Missouri Basin States Association 1985; Hesse 1987). These levees were designed to protect agricultural lands on the floodplain landward of the levee. More than 10,000 ha of old erosion zone lie riverward of the levees in Nebraska. There should have been provision for the lands riverward of the levees to become part of a public corridor for the river's floodplain.

Altered Hydrograph

The precontrol Missouri River carried peak runoff during two periods, March–April and June (Hesse and Mestl 1993). Since 1954, dams on the mainstem and tributaries have eliminated the peaks and produced a flat, metered hydrograph, which has effected reproduction of native fish and aquatic insects (Hesse and Carlson 1992). Moreover, before 1954, flushing flows, known as dominant discharge, occurred every 1.5 years. After

1954, dominant discharge occurred only twice in 33 years. The result has been the stabilization of the channel's morphological configuration. Dynamic change was stopped nearly 40 years ago. Native fish and wildlife used the historical channel components (sandbars, chutes, pools, backups, dunes, islands) as essential habitat.

We recommend a return to a semblance of the natural hydrograph. Initially this change could be based on a daily percentage of the mean annual discharge during a precontrol period. This approach would allow recovery of the seasonality of flows while providing control over the magnitude; however, dominant discharge must be recovered, and development of a floodplain corridor is essential for this process to be restored in part.

Through fine tuning of the navigation channel, as much as two-thirds of the flow of the river during July–October could be stored in the mainstem reservoirs to be used to emulate the spring flood pulse in riverine reaches. We believe this can be done with only minimal effect on full service navigation (Hesse 1992), and the draft results of Master Water Control Manual modelling by the U.S. Army Corps of Engineers suggests that power generation losses will be minimal (U.S. Army Corps of Engineers 1992).

Loss of Sediment Transport

Dams on the mainstem and tributaries have short-stopped the movement of sediment from upstream. The precontrol river was in a state of equilibrium; net sediment entering a reach replaced an equal amount leaving. Sand, silt, and organic matter were the raw materials for habitat development and aquatic nutrition. Precontrol average annual suspended sediment loading was 149 million metric tons at Yankton, South Dakota, and grain size averaged 20% sand, 40% silt, and 40% clay. By 1954, annual suspended sediment loading dropped 81% to 30 million metric tons. The sand fraction more than doubled, while silt and clay were halved (Slizeski et al. 1982). In addition to eliminating much of the material for habitat development, areas downstream from dams and the lower ends of tributary streams have developed severe channel bed degradation. Degradation has contributed to the loss of off-channel habitat and has furthered the severance of the floodplain–channel connection (U.S. Army Corps of Engineers 1991).

We recommend that the U.S. Army Corps of Engineers investigate sediment bypass systems for the Missouri River and its tributaries. Sediment bypass is feasible (Singh and Durgunoglu 1991), and additional benefits such as increased water storage in hydropower reservoirs; elimination of delta formations in the upper end of reservoirs, which can cause lowland flooding; and reduced degradation, which will reduce navigation channel maintenance costs, damage to water intakes and bridge abutments, and head cutting in tributary streams.

Options for study may include operating lake discharge as run-of-the-river for a year, sluice gates (below grade at the dam), sluice bypass channel, and sluice pipeline (on or in the lake bed); for a short-term solution, land adjacent to the river channel just downstream from the dam can be acquired and pushed into the river channel.

Altered Water Temperature

The largest dams on the mainstem of the Missouri River release water from depths of 42 m (Fort Randall Dam) to 59 m (Oahe Dam; U.S. Army Corps of Engineers 1985). Cold bottom strata have significantly altered downstream riverine water temperature.

Water temperature was 21° C at river km 1,112 (on the channelized reach downstream from Sioux City, Iowa) and 23° C at river km 801 on the same day in May 1987, and 26° C at river km 1,112 and 28° C at river km 801 in June 1987. This reach runs nearly straight north and south, and the effect on warming because of latitude would be greatest in this reach. Under the same circumstances, we measured water temperature at river km 1,393 (31 km downstream from Fort Randall Dam) to be 10° C in May 1987 and 16° C at river km 1,178 (216 km nearly due east). Water temperature was 17° C at river km 1,393 and 26° C at river km 1,178 on the same day in June 1987. Thermal modification of this magnitude can affect aquatic insects by altering emergence cues, egg hatching, diapause breaking, and maturation (Petts 1984). Native fish, such as sauger, sturgeon, blue sucker, and others, spawn in response to water temperature, photoperiod, and run-off cues. Today these cues send mixed signals. We recommend that selective withdrawal be incorporated into existing dam-reservoir design. Water could be discharged from near the surface, or bottom water could be mixed with surface water

before release from the existing structure. Construction of a submerged weir upstream from the fixed outlets of these mainstem dams would cause cold bottom water to mix with warmer surface waters before discharge into the river downstream (Cassidy 1989). This may abate some of the effect and should be relatively less expensive than retrofitting the dam with a series of outlets at different elevations on the dam face. If the weir was constructed with quartzite rock it would also serve as an underwater reef with fisheries benefits.

Fish Bypass

Large numbers of paddlefish, blue sucker, and buffalo, as well as most other native fishes, accumulate in the tailwater of Gavins Point Dam, especially in early spring. We have successfully used these concentrations to acquire information about the size and age structure of these fish stocks; however, we have also observed breeding-sized adults, fully ripe, with no hope of finding adequate reproductive substrate in the tailwater.

Gavins Point Dam provides a good opportunity to develop a fish bypass because many fish are attracted to the strong currents in the narrow discharge canal downstream from the powerhouse. Large numbers of fish can be seen swimming along the south wall. A fish elevator could readily be installed on this wall and used in conjunction with a collection and trucking facility on the bank, which would not require alteration of the dam. Such a facility should be cost effective, and an elevator design would work effectively for most native species regardless of size. These species would subsequently be provided access to Lewis and Clark Lake and 72 km of unchannelized Missouri River. We recommend that the U.S. Army Corps of Engineers investigate construction of such a bypass.

Sport and Commercial Harvest Restrictions

Native fish stocks in the riverine portions of the river in Nebraska are only a fraction of their previous size, a result of changes in form and function of the present versus primordial Missouri River. As density declined and habitat shrank, overfishing occurred. First, the largest and oldest specimens were eliminated, and eventually the stocks were damaged (Hesse and Mestl 1990). With few exceptions (i.e., drum, redhorse, carpsucker, goldeye) most native fish stocks of the Missouri River are declining, and harvest cannot be sustained at the present level.

Sport and commercial fishing must not be allowed to overharvest remaining fish stocks. Future recovery depends on the maintenance of native genetic stocks. The harvest of sauger, largemouth bass, crappie, buffalo, blue sucker, and gar should be restricted until survey data indicate that a harvestable surplus can be sustained. Paddlefish, shovelnose sturgeon, blue catfish, and flathead catfish reproduction is not highly successful, but because they are long-lived and slow-growing, they seem more numerous than other stressed species. Harvest of these fishes should be limited and controlled. Paddlefish harvest has been closely managed in recent years, and the population in Nebraska appears to respond to careful management.

Needed Research

Future research should be focused on evaluation of implemented restoration design. The deteriorated condition of many native species indicates the need for implementation of a comprehensive management plan. Much is already known about Missouri River ecosystem function; the time has arrived to implement real restoration.

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Secondary Production of Aquatic Insects in the Unchannelized Missouri River, Nebraska

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Abstract. We studied secondary production (amount of biomass produced over time) of aquatic insects in selected backwater habitats of the Missouri River. We combined our results with the results of previous studies in other habitats to examine changes in production over time. Diptera contributed more than 50% of annual production in almost all backwater habitat types, although other groups, including Ephemeroptera and Trichoptera, contributed significantly to production of specific habitats in selected years. Production for a 93-km section of unchannelized Missouri River declined 61% between 1963 and 1980. In 1963, 51,003 kg of secondary production originated from main channel, chute, and backwater aufwuchs habitat; this declined by 71% to 14,722 kg by 1980.

Before the construction of the mainstem dams and navigation channel, the Missouri River had many side channels and associated backwaters. This habitat has nearly disappeared because of reservoir impoundment, channelization, and severe channel bed degradation downstream from the dams. Backwater habitat that remained was affected by water management from the reservoirs for other purposes, such as navigation, flood control, and hydropower production. Little is known about how water management affects the biotic components of the Missouri River. The Nebraska Game and Parks Commission has undertaken studies to examine how the loss of backwaters and altered water management affect the various abiotic and biotic components of the Missouri River. This paper summarizes a study of the secondary production of aquatic insects from one Missouri River backwater. We combined our results with those of previous studies (Langemeier 1965; Namminga 1969; Volesky 1969; Nord 1971; Gould 1975; Dixon 1986) to examine changes in secondary production over time in the unchannelized Missouri River.

Backwater Study Area

The study was conducted on the Bazile Creek Wildlife Management Area, located along the Missouri River in Knox County, Nebraska. It is among the last remaining seminatural backwaters on the Missouri River. The Bazile Creek Wildlife Management Area consists of 485 ha of wetlands (cattail, *Typha augustifolia* L.; willow, *Salix* spp.; arrowhead, *Sagittaria* spp.; *Potamogeton* spp.; reed canarygrass, *Phalaris arundinacea* L.; and Canada wild rye, *Elymus canadensis* L.) and 452 ha of open

pools, lakes, chutes (open at both ends), and backups (closed at the upper end) that connect directly with the main channel of the Missouri River. The presence and condition of this habitat are directly related to main channel flow in the Missouri River. At low stage, little vegetation and only the deeper lakes and chutes remain inundated, whereas at high stage there is movement of water over the entire backwater area. The backwater habitat of the Bazile Creek Wildlife Management Area consists of submerged, vegetated sand bars (<1.0 m deep, dominated by emergent macrophytes); pools and lakes (<1.4 m deep, with or without current); chutes (<2.3 m deep, with continuous current); backups (old chutes with the upper end cut off, <2.1 m deep and no current); and submerged trees and brush.

Backwater Study Methods

We established transects on a vegetated sand bar, pool, lake, and chute in 1985. A second chute transect was added in 1986. In addition two transects were established in a second pool and two transects were established in each of two different backups in 1986. Benthic communities were sampled with two Ekman dredges (15.24 × 15.24 cm, 22.86 cm deep and 30.5 × 30.5 cm, 30.5 cm deep) mounted on handles, and a weighted Peterson dredge (19.05 × 36.83 cm). Aufwuchs were sampled with modified Hester-Dendy multiplates (Hester and Dendy 1962). These samplers consisted of 10 circular 7.62-cm diameter hardened tempered pressboard discs mounted on a 20.32 × 0.64-cm eye bolt and separated by 0.64-cm washers. The number of washers used determined the spacing of disks; from the top, 5-4-3-2-2-2-2-2-2 washers were used. These multiplates were attached to a floating platform in an area of open water with low current at ice out, which occurred during March. Dredge and Hester-Dendy multiplate samples were collected every 3 weeks in 1985 and monthly in 1986 and 1987 during the openwater season. Four replicate Hester-Dendy multiplates were collected each sampling period. Nine replicate dredge samples were collected in 1986 from each transect and combined in the field. Five replicate dredge samples were collected in 1986 and 1987 at randomly selected distances along each transect, preserved separately, and identified by station, distance, and depth. Dredge samples were sieved in the field using 533-μ-mesh sieves to remove the inorganic fraction, and all samples were preserved with 10% buffered formalin. Multiplate samplers were collected in 4-L jars and preserved with 10% buffered formalin.

Dredge samples were rinsed using 533-μ-mesh sieves in the laboratory to remove all remaining sediment and were then sorted by hand. We made a sugar solution (specific gravity 1.10) to assist in removal of aquatic insects. Multiplate samplers were disassembled and scraped. All insects were identified to family. Selected common taxa were identified to genus. Insects not measured, including Hemiptera, Coleoptera, Diptera, and miscellaneous Trichoptera and Ephemeroptera, were grouped by station and year. Head-capsule diameters were measured to the nearest 0.1 mm with an eyepiece micrometer for selected common taxa. Intact specimens were grouped by size class and used to determine the average weight of individuals for each size class. All insects were dried to a constant weight at 105° C and weighed to the nearest 0.01 mg.

We calculated production by the size–frequency method for those insects that were measured and had an annual standing stock greater than 0.01 g/m^2 (Hynes 1961; Hynes and Coleman 1968; Hamilton 1969; Benke 1979). The computer program of Krueger and Martin (1980) was used to calculate production and confidence limits. Increased precision of production estimates was gained by incorporating a Cohort Production Interval (CPI) in the analysis. The CPI adjusts the production value if the cohort is present for a period longer or shorter than a year (Benke 1979). We used a combination of empirically derived CPI's and those reported in the literature (Table 1). For all other insects (those not measured and with a standing stock less than 0.01 g/m^2) production was calculated by the annual production–biomass ratio method (P–B) (Waters 1979; Parker and Voshell 1983). Mann (1967) predicted that for benthic insects the annual P–B ratios would be about 2 for semivoltine species, 5 for univoltine, and 10 for multivoltine populations.

Backwater Study Results

At Bazile Creek Wildlife Management Area, benthic production on the vegetated bar habitat was dominated by Diptera and Caenidae, which together accounted for 70.1–91.3% of annual production (Table 2). Diptera contributed at least 36.7% of the production in the lake and pool habitat in all years (Table 3), although *Hexagenia* and Caenidae contributed 50.4% in the pool and 45.0% in the lake habitat in 1985. Important taxa in the

Table 1. Biotic community (A = aufwuchs, B = benthic), cohort production interval (CPI), and voltinism (M = multi, S = semi, and U = uni) used in production calculations (Lyman 1955; Minshall and Minshall 1966; Cowell and Hudson 1967; Swanson 1967; Hall et al. 1975; Edmunds et al. 1976; Mackay 1979; Hall et al. 1980; Lund and Peters 1981; Parker and Voshell 1981; Mackay 1984; Merritt and Cummins 1984; Corkum 1985; Dixon 1986; Ernst and Stewart 1986).

Taxon	Community	CPI	Voltinism
Ephemeroptera			
Tricorythidae	A,B	50	M
Caenidae	A,B	175	M
Hexagenia	B	716	S
Miscellaneous	A,B	365	U
Odonata			
Gomphidae	B	730	S
Coenagriidae	A	350	U
Hemiptera			
Miscellaneous	B	365	U
Plecoptera			
Perlodidae	A	240	U
Trichoptera			
Neureclipsis	A	106	M
Hydropsyche	A	168	M
Potamyia	A	168	M
Miscellaneous	A	365	U
Coleoptera			
Miscellaneous	B	365	U
Diptera			
Miscellaneous	A,B	182	M

chute habitat included Diptera, Trichoptera, and, in individual years, *Hexagenia* and Gomphidae (Table 2). Diptera and Caenidae also accounted for more than 95.6% of annual production in the backup habitat in each year (Table 3). Aufwuchs production was dominated by Trichoptera, especially *Neureclipsis*, which contributed 73.6% of annual production (3-year average), followed in importance by Diptera, 10.9%, and Caenidae, 4.8% (Table 2). Confidence limits for production estimates calculated using the size–frequency method ranged from 20.2% to 76.9% and averaged 50.01%.

Annual production was lowest on the Hester–Dendy plates in 1985 (Table 2) followed by the chute habitat in 1985 and 1986. The highest production occurred in the backup habitat in 1986 (Table 3), in the lake habitat in 1987, and on the Hester–Dendy plates in 1986 (Table 2). In all habitats, one or two taxa accounted for 69–99% of the annual production. Diptera accounted for more than 50% of the benthic production estimates in all years and habitat types except for the lake and pool in 1985 (Table 3), where Ephemeroptera was the dominant group.

Historical Changes Methods

Secondary production of the unchannelized Missouri River in our backwater study was compared with previous studies that had examined main channel habitat (Langemeier 1965; Namminga 1969; Nord 1971; Gould 1975; Dixon 1986), chutes (Langemeier 1965; Volesky 1969; Nord 1971; Gould 1975), and backwaters (Volesky 1969; Dixon 1986). To standardize the production estimates for all studies when taxonomic groups were similar and P–B ratios and CPI values were comparable, we used published production estimates. Otherwise, we calculated production from reported annual standing stock estimates using the P–B method and the same values for P–B ratios and CPI values used for our data (Table 1).

Production for the entire reach from Gavins Point Dam to Ponca State Park, Nebraska, for 1963 and 1980 was determined in the following manner. Schmulbach et al. (1981) measured areas of the different aquatic habitat types found in this reach of the Missouri River in 1980. Using maps and aerial photographs we estimated the average annual loss of aquatic habitat to be 0.88% from 1980 to 1988. Because this rate of change was still occurring after much of this reach had been stabilized during the period 1955–65, we used this rate to conservatively estimate that the aquatic area of the Missouri River was 15% greater in 1963 than in 1980. Morris et al. (1968) estimated that in this same reach in 1963 there was 84.2% main channel and 15.8% chute–backwater habitat. We used the estimated areas of main channel and chute–backwater and Morris' percentages to estimate the area of each habitat type in 1963. The measured channel length in 1980 was 93,000 m (Schmulbach et al. 1981). We doubled this estimate for both banklines and calculated the amount of each bankline type from aerial photographs, maps, and visual inspection. We estimated the amount of chute bankline by dividing the area of chute habitat in 1963 and 1980 by a mean chute width of 144 m, which was obtained from maps. No investigator has studied benthic production for the habitat that Schmul-

Table 2. Annual production (mg/m^2) for aquatic insects from backwater vegetated bar and chute habitats and from Hester-Dendy plates from the Missouri River, 1985–87.

Taxon	Vegetated bar			Chute			Plates		
	85	86	87	85	86	87	86	86	87
Ephemeroptera									
Tricorythidae	4	14							
Caenidae	17	688[a]	125	<1	1	209	9	127	140[a]
Hexagenia	15	13	14	89	1	<1	<1		
Miscellaneous	2	2	40						
Odonata									
Gomphidae	107	<1	4	24	6				
Coenagriidae	26	45	<1	<1	33	<1	162[a]	75[a]	
Hemiptera									
Miscellaneous	13	24	85	11	<1	7			
Plecoptera									
Perlodidae	41[a]								
Trichoptera									
Neureclipsis	24	38	33	47	11	274	160	2,049[a]	1,239[a]
Hydropsyche	13	17	21	363[a]	50				
Potamyia	10	56	16	62[a]					
Miscellaneous	5	5	1	5	551	15			
Coleoptera									
Miscellaneous	15	24	<1	15	<1				
Diptera									
Miscellaneous	468	831	808	182	191	536	22	521	194
Total	685	1,663	1,073	361	309	1,080	268	3,782	1,777

[a] Production calculated by the size-frequency method.

Table 3. Annual production (mg/m^2) for aquatic insects from backwater backup, lake, and pool habitats from the Missouri River, 1985–87.

Taxon	Backup		Lake			Pool		
	86	87	85	86	87	86	86	87
Ephemeroptera								
Tricorythidae	24	8	11	13				
Caenidae	128[a]	120[a]	11	10	6	41	123[a]	83[a]
Hexagenia	18	16	366	14	1,321	209[a]	49	
Miscellaneous	2	12	18					
Odonata								
Gomphidae	15	12	5	1	6	7	13	
Coenagrionidae	8	7	2	4	30	16		
Hemiptera								
Miscellaneous	46	16	23	21	32	83	107	75
Trichoptera								
Neureclipsis	<1	3	62	2	59	25		
Hydropsyche	31	<1	5	23				
Potamyia	<1	1						
Miscellaneous	10	2	2	1	15			
Coleoptera								
Miscellaneous	110	27	7	11	80	205		
Diptera								
Miscellaneous	4,450	2,452	307	752	4,609	1,221	1,621	1,788
Total	4,786	2,655	838	798	4,649	2,702	2,282	2,306

[a] Size calculated by the size-frequency method.

bach et al. (1981) described as main channel border, so the production value for main channel mud bank or main channel pool was used for this habitat.

Aufwuchs habitat was estimated by measuring the surface area of all woody materials along measured distances (25–300 m) of eight different bankline types (mature woodlands—trunk diameters >150 mm; immature woodlands—trunk diameters <150 mm; vegetated sandbars; wooded bluffs; cleared banklines; mature woodlands—trunk diameters >150 mm with stabilized banks, wooded bluffs with stabilized banks, and cleared banklines that had been stabilized. This habitat was expressed as square meters of aufwuchs habitat per meter of bankline.

Historical Changes Results

Our backwater data along with the previously reported production values (Langemeier 1965; Namminga 1969; Volesky 1969; Nord 1971; Gould 1975; Dixon 1986) were used to calculate the mean annual production of aquatic insects for each habitat type found in the unchannelized Missouri River (Table 4). Reported values from different studies for the same habitat type were similar (Table 4). Main channel and chute aufwuchs habitat, with current velocities greater than 0.1 m/s, had the highest annual production, 42.4 and 68.8 g/m^2 (Table 4). The lowest annual production was found in the main channel mudbank or pool benthos, 0.1 g/m^2 (Table 4).

Production of aquatic insects from aufwuchs habitat on the Missouri River declined 71% between 1963 and 1980 (Table 5). Aufwuchs habitat contributed 51,003 kg of aquatic insects in 1963 and 14,722 kg in 1980. Benthic production dropped 32%, from 17,869 kg of insect production in 1963 to 12,138 kg by 1980 (Table 6). Total production declined 61% from 68,872 kg in 1963 to 26,860 kg in 1980 for the 93-km section of unchannelized Missouri River. System production in the Missouri River in 1963 was 1.01 g/m^2; this declined to 0.47 g/m^2 by 1980.

Table 4. Production estimates (g/m^2), annual (combined by weighted average) and by individual study (weighted average) for benthic and aufwuchs aquatic insect communities from habitats of the Missouri River (water velocity = v).

Community/habitat	Production (annual)	Production	References
Benthos			
Chute (v = all)	0.44	0.31	Langemeier 1965
		0.13	Volesky 1969
		0.58	Present study
Vegetated bar (v = all)	1.14		Present study
Backwater (v = all)	2.40		
		0.59	Volesky 1969
		2.63	Present study
Main channel (v >1.3 m/s)	0.19		
		0.16	Langemeier 1965
		0.20	Namminga 1969
Main channel pool (v <0.5 m/s)	0.10		Langemeier 1965
Aufwuchs			
Chute (v <0.1 m/s)	14.21		
		12.95	Nord 1971
		20.50	Gould 1975
Chute (v >0.1 m/s)	68.78		Dixon 1986
Vegetated bar (v = all)	1.27		Volesky 1969
Backwater (v = all)	2.21		
		3.02	Dixon 1986
		1.94	Present study
Main channel border (v >0.4 m/s)	42.39		
		42.37	Nord 1971
		43.70	Gould 1975
		41.21	Dixon 1986

Table 5. Estimated bankline length (m), multiplication factor, and annual production (kg) of aquatic insects from woody attachment substrates from the Missouri River in 1963 and 1980.

Bankline type	Factor	1963 Length	1963 Production	1980 Length	1980 Production
Mature woodlands	4.57[a]	141,200	27,356	33,700	6,529
Immature woodlands	4.86	23,400	4,821	19,900	4,100
Vegetated sandbars	0.17	44,800	323	38,100	275
Wooded bluffs	1.91	9,400	761	7,300	591
Cleared bankline	0.29	33,000	406		
Mature woodlands with stabilized bankline	0.18	22,100	169		
Wooded bluffs with stabilized bankline	0.18	700	5		
Cleared and stabilized bankline	0.06	31,200	79		
Chute	3.59[b]/1.54[c]	116,200	17,309	38,000	2,428
Total		335,000	50,570	224,000	14,582

[a] Includes all bankline cleared or stabilized in 1980.
[b] Weighted average of all main channel bankline types in 1963.
[c] Weighted average of all main channel bankline types in 1980.

Table 6. Estimated area (ha) and annual production (kg) for the benthic and aufwuchs insects communities from Missouri River aquatic habitats in 1963 and 1980.

Community/habitat	1963 Area	1963 Production	1980 Area	1980 Production
Benthos				
Main channel and sand bar	5,097	9,786	4,829	9,272
Main channel mud bank, pool, and border	353	353	338	338
Chute	836	3,670	274	1,203
Backwater, vegetated bar	34	388	11	125
Backwater, open water	153	3,672	50	1,200
Total	6,473	17,869	5,505	12,138
Aufwuchs				
Backwater, vegetated bar	34	433	11	140
Main channel and chute border	305[a]	50,570	204[a]	14,582
Total	339	51,003	215	14,722
Total	6,812	68,872	5,720	26,860

[a] Based on an average border width of 9.1 m (Schmulbach et al. 1981).

Discussion

Secondary production in the only remaining unchannelized reach of Missouri River downstream from the mainstem dams declined 61% from 1963 to 1980 (Table 6). The source of this production also changed. Backwater habitat, which has disappeared because of reduced flooding and increased degradation, may have contributed disproportionately to the production of the Missouri River. Clear water coming from the dams has caused severe channel bed degradation, which subsequently drained many backwaters. In 1963 chute and backwater habitat contributed 37% of the secondary production; this dropped to only 19% by 1980. More importantly, the actual biomass of insects produced in chute and backwater habitat dropped 80% from 1963 to 1980. The loss of backwater habitats and their insect communities is important because native fish use these areas as feeding sites apart from the higher velocity water of the main channel (Hesse and Mestl 1985; Dames et al. 1989).

In the precontrol Missouri River, channel meandering caused trees and root masses to fall into the

river, providing high quality aufwuchs habitat. Chittenden (1962) recounted that in 1838 two steam-powered snag boats removed 2,245 huge trees from only 524 km of main channel and cut away over 1,700 more hanging from the bank. After channel meandering was stopped, this source of aufwuchs habitat was lost. The combination of stabilized banklines and channel bed degradation has substantially reduced remnant aufwuchs substrates. Main channel and chute border aufwuchs habitat contributed a disproportionate 73% of the secondary production in the unchannelized Missouri River in 1963 (Table 5). Because system productivity is closely aligned with available aufwuchs habitat, the elimination of such substrate can be expected to have an enormous effect on production in the Missouri River. Morris et al. (1968) and Namminga (1969) noted the almost complete dissimilarity between the drift and benthic communities of the Missouri River. Both researchers commented that the drift was made up mostly of insects that colonized aufwuchs habitat. Morris et al. (1968) determined that 525.7 kg of organisms drifted past a site in the unchannelized Missouri River in 24 h in 1963. By 1984 this drift biomass had dropped to 125.3 kg in 24 h (Hesse and Mestl 1985). These data support our observation that aufwuchs habitat is essential for Missouri River insect community development.

Production of aquatic insects in the Missouri River was compared to that found in the Satilla River in Georgia (Benke et al. 1984) and the Sand River in Alberta (Soluk 1985). Although these rivers are not exactly similar to the Missouri in size, location, or physicochemical parameters, they are the most similar of the few large rivers that have been studied. The Satilla River was selected because similar methods of calculating production were used and it contained habitat types that compared to habitats studied on the Missouri River. The Sand River was selected because both it and the Missouri have large areas of shifting sand. Total annual insect production at two Satilla River sites was 33.52 g/m^2 and 16.84 g/m^2 (Benke et. al. 1984) compared with 1.01 g/m^2 in 1963 and 0.47 g/m^2 in 1980 in the Missouri River. Production in benthic habitats in the Missouri River was much lower than in the Satilla River. Muddy benthos (our backwater habitat) insect production (16.16 g/m^2 and 5.51 g/m^2) in the Satilla River (Benke et al. 1984) was two to eight times higher than that (2.40 g/m^2) of insect production in the Missouri River (Table 4). In sandy benthos substrate (our main channel habitat) this difference was even more dramatic, 0.19 g/m^2 of insect production in the Missouri River (Table 4) and 26.40 g/m^2 and 11.74 g/m^2 in the Satilla River (Benke et al. 1984). Production in sandy benthos substrate in the Missouri was much more similar to production found in the Sand River (0.75 g/m^2, Soluk 1985). Differences in current velocities between these three rivers may partially explain these differences in production. Current velocity in the main channel of the Satilla River ranged from 0.2 to 0.9 m/s (Benke et al. 1984) and from 0.6 to 1.5 m/s in the Sand River (Soluk 1985), whereas that in the Missouri River was greater than 1.3 m/sec (Langemeier 1965; Namminga 1969). Higher current velocities create continuously shifting sand areas, which seem to limit production. Production on aufwuchs habitat in the main channel of the Missouri River averaged 42.39 g/m^2 (Table 4). This is similar to insect production on snag habitat at two Satilla River sites, 72.24 g/m^2 and 57.42 g/m^2.

Productivity of the Missouri River is a complex interaction of many factors and must be examined in the context of the ecosystem in which it functions. Fish production can be better understood and managed when factors affecting secondary production are defined. These data suggest that changes in the Missouri River within the last 30 years have had an effect on the amount and sources of secondary production. Fish populations, especially native species, are declining in the Missouri River (Hesse et al. 1993). The availability of aquatic insects has contributed to the decline in fish abundance. The restoration of snags and organic matter into the Missouri River will effectively increase secondary production and eventually fish biomass. Other remedial actions should include restoration of sediment transport, recovery of natural water temperatures timed according to the historical seasonal patterns, reconnection of cut-off channel features (i.e., chutes, backwaters, riparian wetlands, forest), and recovery of a semblance of the natural hydrograph (Hesse et al. 1993).

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Restoring Physical Habitat in the Missouri River: A Historical Perspective

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Abstract. In the last 80 years the natural hydroperiod and channel geometry of the Missouri River have been highly altered from their natural state by the construction and operation of six large mainstem dams. Alterations in physical habitat have been indicated as major reasons for changes in the native warmwater riverine fish community. Physical habitat conditions in the aboriginal Missouri River and in the present river are described and contrasted by comparing flow conditions between predam and postdam cross sections. By understanding alterations in both microhabitat and hydroperiod in the Missouri River, it is possible to formulate hypotheses that account for changes in the native warmwater community, particularly for the decline of some species. The modeling tools and approaches used to describe the alterations in physical habitat can also be used to guide potential restoration efforts in the Missouri River or to restore other heavily affected streams and rivers in the Mississippi River basin.

The present-day Missouri River aquatic ecosystem is highly modified from presettlement times (Funk and Robinson 1974; Hallberg et al. 1979; Pfleiger and Grace 1987; Hesse et al. 1988; Hesse et al. 1989). Construction of six large mainstem dams in the upper basin and channelization of the lower 1,300 km have changed the hydrologic pattern and the channel morphology of the river. Along with changes in temperature regime and turbidity, the available habitat for the aquatic community has changed. These changes are thought to have contributed to the decline in the native fish fauna, as evidenced by the listing or candidate status of six endemic fish species under the federal Endangered Species Act (Pfleiger and Grace 1987).

Hesse et al. (1993) documented the dramatic declines in some endemic fishes of the Missouri River. Pfleiger and Grace (1987) provided a historic chronology of a changing fish community in the lower Missouri River. The change in flow regime has not been as dramatic in that reach, but channelization has changed the depth and velocity patterns.

Efforts are underway to restore aquatic habitat along portions of the Missouri River. The Missouri River mitigation project will include restoring various chutes and backwaters along the channelized reaches of the river. Also the U.S. Army Corps of Engineers is cooperating with a local government to restore a chute near Omaha, Nebraska. In addition, alternative water management scenarios are being evaluated by the U.S. Army Corps of Engineers for the mainstem dams. Criteria are needed that define characteristics of the aquatic habitat that support the endemic fish community on the Missouri River.

Research done in small warmwater streams indicates that depth and velocity distributions are important in defining fish community structure. Bain and Boltz (1989) summarized research done on patterns of habitat use in warmwater fish communities in streams and concluded that, generally, depth and velocity characteristics were important in determining fish community characteristics. Gorman and Karr (1978), for instance, determined that the fish community characteristics were dependent on the distribution of habitat (defined in combinations of depth, velocity, and substrate). They concluded that modifications of these variables would, over time, change the structure of the fish community. Schlosser (1987) developed a conceptual model outlining the processes that determine community structure in small warmwater streams. In this model, species composition and age classes were determined by the level of habitat heterogeneity (depth, velocity, and substrate).

For this paper, we assumed the endemic fish community in the Missouri River is dependent on the combinations of depth, velocity, and flow patterns found in the river. We also assumed that in part the changes in the Missouri River fish community are the result of changes in these patterns.

We described natural conditions using preregulation cross-section data and an estimate of the mean monthly preregulation hydrograph to quantify depth and velocity distributions below Gavins Point Dam during late summer and fall. We then compared the regulated condition to the preregulation condition for the same months to demonstrate how available physical habitat may have changed from preregulation times.

The physical and hydrologic characteristics of the preregulation Missouri River can serve as criteria to be used to design various restoration projects. In addition, the relative effects of various water management decisions can be determined by comparing the physical and hydrologic characteristics of different alternatives to the unmodified condition.

Physical habitat is only one factor that affects fish population levels. However, proposed restoration efforts, as well as alternative flow regimes, will

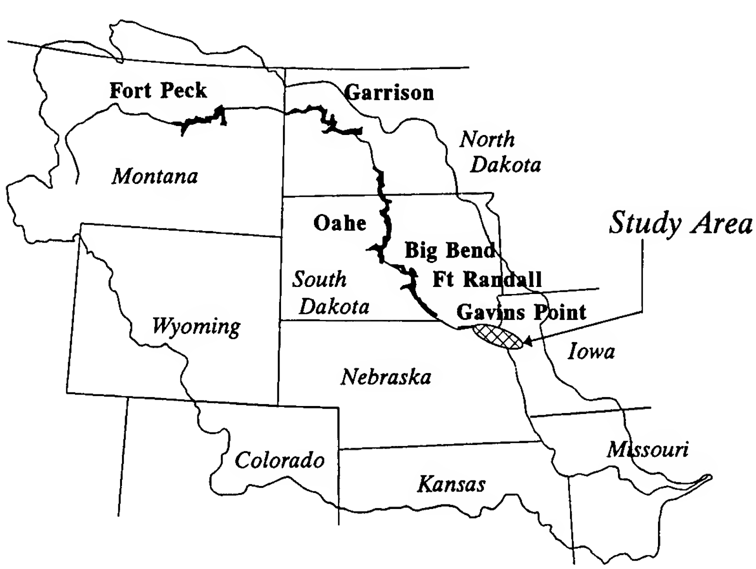


Fig. 1. Study area in relation to the six Missouri River mainstem reservoirs.

alter the factors that determine available physical habitat, that is, discharge, depth, and velocity

Study Area

The flows in the Missouri River are regulated by a system of six large mainstem reservoirs (Fig. 1). The system is operated to provide for flood control, hydroelectric generation, navigation, irrigation, recreation, fish and wildlife, and municipal and industrial water supply (Sveum 1988). Gavins Point Dam is the most downstream dam in the system.

The river reach for 88 km downstream from Gavins Point Dam is still in a relatively natural state. The river ranges from 305 m to 1,500 m in width. The reach has not been channelized, and major bank stabilization has not taken place. Many of the habitat features of the unaltered Missouri River remain. Schmulbach et al. (1981) provided a summary of the major aquatic habitat types in this reach. The river downstream of this reach to the mouth has been extensively modified by channelization or bank stabilization.

Water levels have been recorded at gaging stations 8 km downstream of Gavins Point Dam at Yankton, South Dakota, since 1930 and 80 km downstream at Ponca, Nebraska, since 1974. The first mainstem dam became operational in 1937 and the last in 1963. The reservoir system filled in 1967.

Methods

Historic Cross-section Data

The U.S. Army Corps of Engineers began measuring cross sections (transects) in the vicinity of the dams shortly before or immediately after construction of each of the dams. The cross sections measure the elevation of the river bottom along a transect perpendicular to the river flow. Gavins Point Dam was closed in 1955, and the first extensive cross-section surveys were done from 1955, to 1957 as a baseline for measuring future channel degradation and aggradation. About 40 cross sections have been surveyed at the same locations every 5–7 years since that time. While only a snapshot in time, these cross sections represent the channel morphology before the influence of the dams. We assumed that the transects represented the preregulation channel morphology.

Transect information, concurrently measured water surface elevations, and simulated unregulated discharge from 1898 to 1990 were used to quantify the seasonal patterns of high flow and the distribution of depths and velocities in late summer and fall.

Historic Hydrology

Actual discharge records for the period before construction of the reservoirs is lacking for many locations on the river. Unregulated monthly flows near Gavins Point Dam, as well as other locations on the river, have been synthesized by the U.S. Army Corps of Engineers, Reservoir Control Center (U.S. Army Corps of Engineers 1993). The simulated period of record is from 1898 to 1990. The database has been developed over many years using a variety of techniques. Flows that were exceeded 25, 50, and 75% of the time were determined for each month by frequency analysis of the monthly values.

Existing Hydrology

Monthly discharge for the regulated condition was obtained from the Reservoir Control Center for Gavins Point Dam for the same period of record as the historic condition (1898 to 1991). The regulated condition was determined by simulating operations as if the reservoirs had been in place since 1898.

Current Cross Sections

Cross sections for the existing conditions were measured twice, once in March 1989 and again in July 1989. Depths, velocities, and multiple water surface elevations were measured at each transect.

Transect Selection

For both conditions, regulated and unregulated, the 40 transects below Gavins Point Dam were separated into one of four groups based on their total width. Transects were separated into groups by width because the occurrence of eight major habitat types (as defined by Schmulbach et al. 1981) on any transect was dependent on the width of the transect. That is, narrow transects had the fewest habitat types present, and wide transects had all eight habitat types present. Two transects from each group were randomly selected to represent the physical habitat in the river. The purpose of this selection process was to describe the lateral variation in habitats at a range of flows in the

proportion that they occur in the entire reach from Gavins Point Dam to Ponca, Nebraska.

Water Surface Elevations, Depth and Velocity Distributions

Water surface elevations were estimated for a range of flows at each transect for the predam and postdam conditions using a calibrated HEC-2 standard step backwater model (Hydrologic Engineering Center 1990). This hydraulic model uses Manning's equation and measured water surface elevations for known discharges to predict water surface elevations along a river course for a range of discharges.

Cross-section data and predicted water surface elevations were used as input to run the IFG4 hydraulic model of the Physical Habitat Simulation System (Milhous et al. 1989). This model predicts depths and velocities across the transect for a range of discharges by calibrating to measured data using a variation of the "single velocity calibration data set" in which two velocity calibration data sets were employed to calibrate the model (Milhous et al. 1989). One set was collected near the lower range of anticipated discharges (approximately 10,000 cfs), and the second was collected near the upper range of anticipated discharges (approximately 30,000 cfs). The low flow calibration data set was used to simulate discharges ranging from 6,000 to 16,000 cfs, and the high flow calibration set was used to simulate discharges ranging from 20,000 to 50,000 cfs. Each flow data set was run separately, and the outputs of the two runs were concatenated to produce velocity predictions spanning the range of discharges for each month. This approach has been proven to generally provide more reliable velocity predictions than other methods within the PHABSIM system for simulating velocities (Milhous et al. 1989).

No velocity measurements were available for the historic condition to calibrate to, so a correction factor was developed for velocities predicted by the IFG4 program. The IFG4 program can synthesize velocities based on the hydraulic radius of each cell if velocity calibration data are unavailable. However, synthesized velocities are usually less accurate than velocities based on velocity calibration data. Velocity correction factors were used to reduce the errors associated with using hydraulic radius to synthesize preproject velocities. Velocity correction factors that could be applied to the preproject data sets were obtained by running the IFG4 program on the postproject data set both with and without velocity calibration data. Each run was then summarized by discharge and channel category as a set of velocity cumulative frequency distributions. The differences, or residuals, between the two runs represent the error in using hydraulic radius to predict velocity distributions for each transect and each discharge. The residuals were fitted to a quadratic equation (Fig. 2), and then the quadric was added back to the appropriate transects and discharges in the preproject data set. The final accuracy of the correction factor is not completely known; however, we feel the correction factor increased the accuracy of the velocity predictions in the preproject data set because (1) the same locations were used for preproject and postproject transects, (2) the same discharges were routed through pre- and post-project transects, and (3) the transect category with the largest residuals (narrow channel category) had similar depth distributions between the preproject and postproject cross sections, and the rate of increase in stage as discharge increased was similar between the preproject and postproject cross sections for the narrow channel category. A complete description of the method for developing the correction factor can be found in Nestler et al. (1993).

Depth and velocity distributions were compared for the August through November months for the median flow for the unregulated and existing conditions.

Results

Annual Hydrograph

The preregulated hydrograph is characterized by low flows in late summer and winter and high flows in spring and early summer (Fig. 3). Variation in monthly flow was greatest during June. The highest flows occurred in June and the lowest in December. The regulated hydrograph reflects the flood control and navigation operations of the system (Fig. 4). High spring flows are reduced, and the low summer and fall flows are increased.

Depth and Velocity Distributions

In the late summer and fall before regulation, simulations indicate that 98% of the channel was less than 3 m deep during median flow conditions (Fig. 5). In contrast, under the regulated condition, simulations indicate 13% of the channel is 3 m deep or greater. Apparently, depths of 0.6–2 m were more frequent and depths of 2–5 m less frequent or

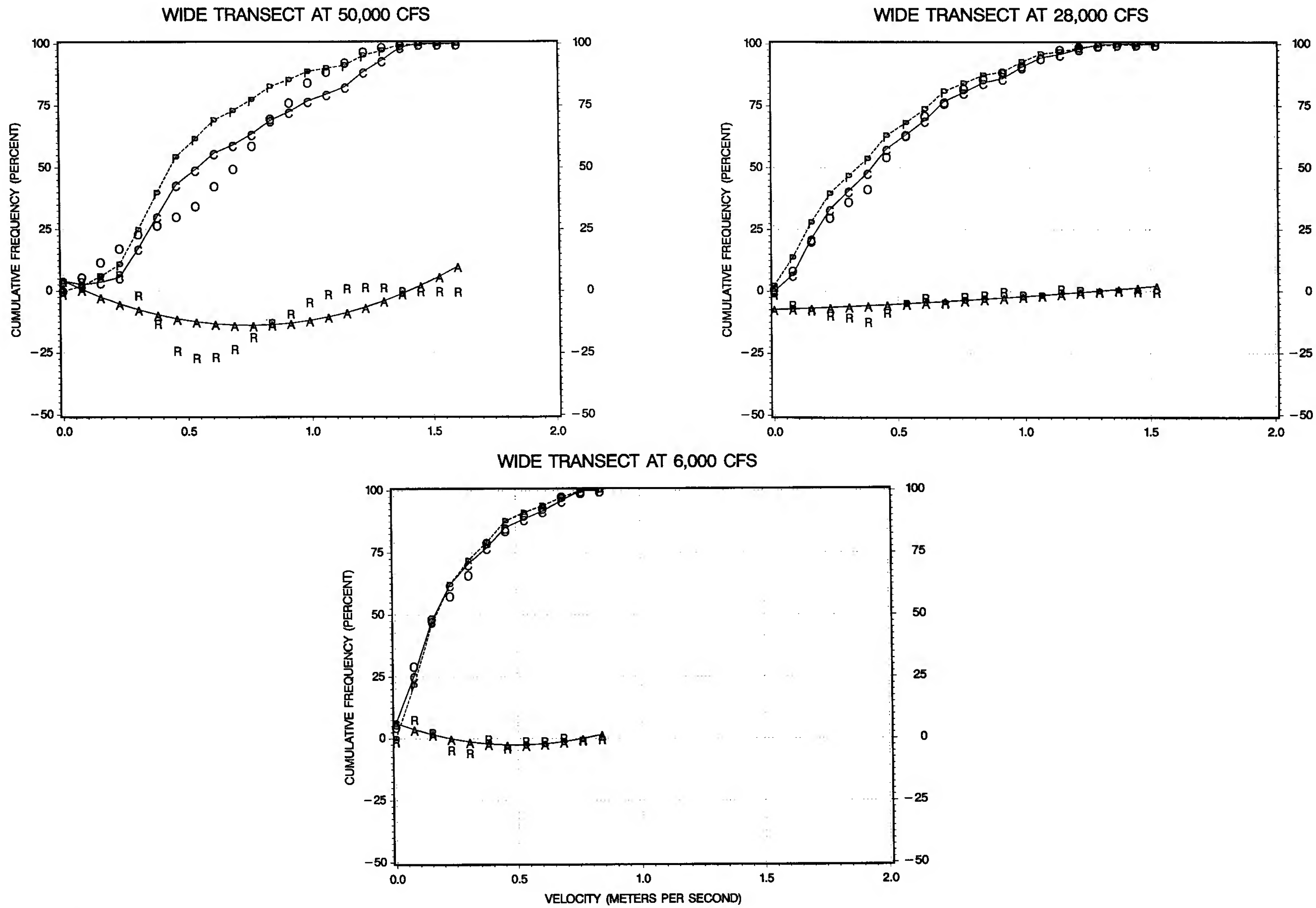


Fig. 2. Plots of velocity predictions as cumulative frequency distributions for narrow and wide transects based on hydraulic radius (P), velocity calibration data (O), and predictions corrected (C) using a quadratic equation (A) fitted to residuals (R). Note that the correction factor (A) generally improves the velocities predicted using hydraulic radius (P), particularly where discrepancies with velocities predicted using velocity calibration (O) data were greatest.

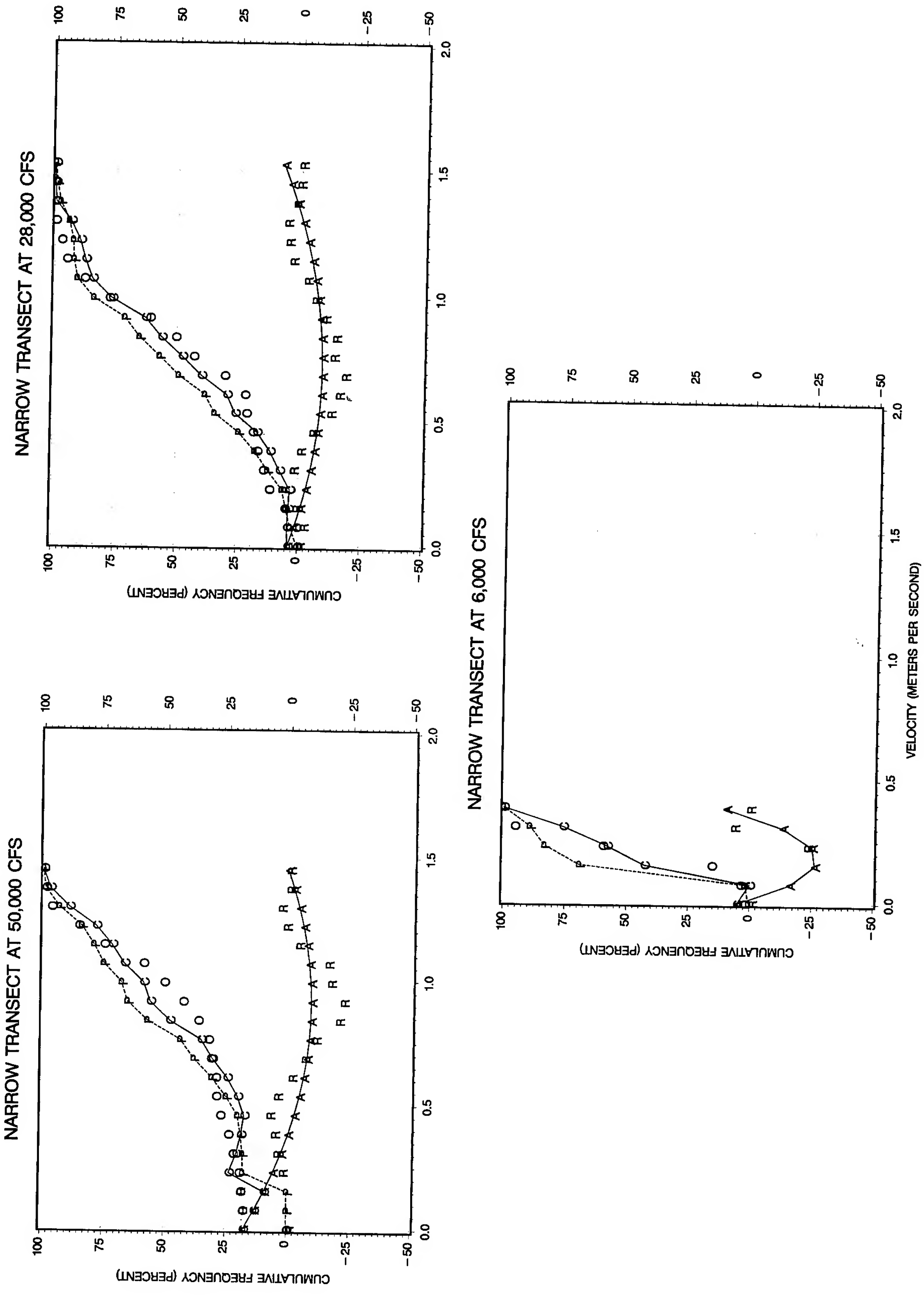


Fig. 2. Continued.

Fig. 3. Synthesized preregulation flows that are exceeded 25, 50, and 75% of the time for each month for the period 1898–1990.

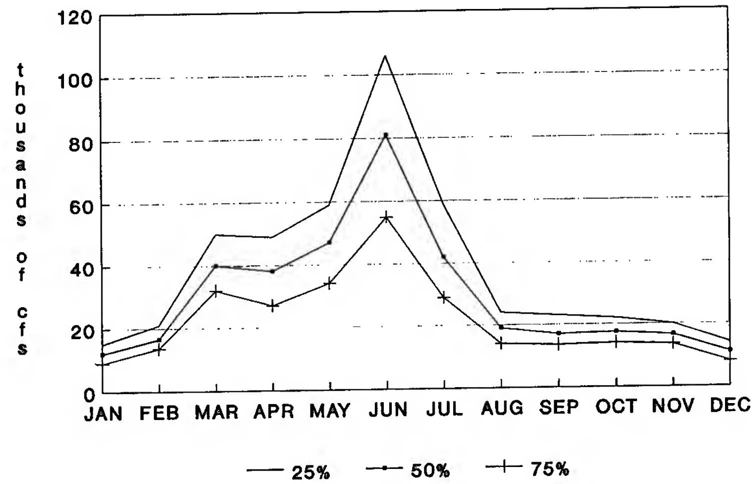


Fig. 4. Synthesized regulated flows that are exceeded 25, 50, and 75% of the time for each month for the period 1898–1990.

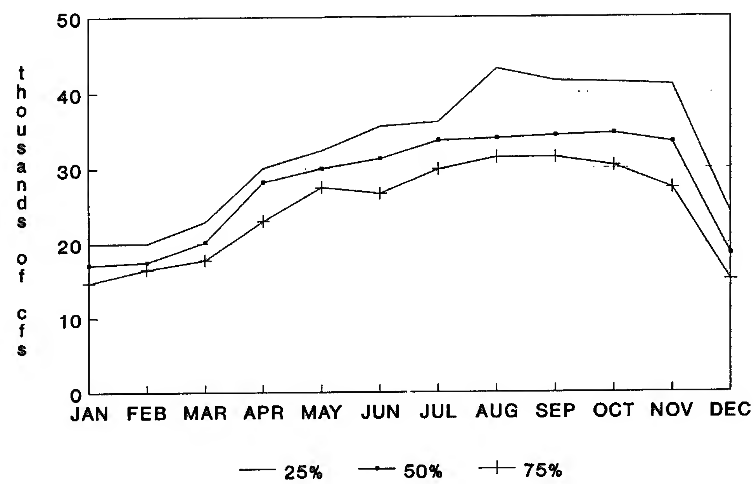
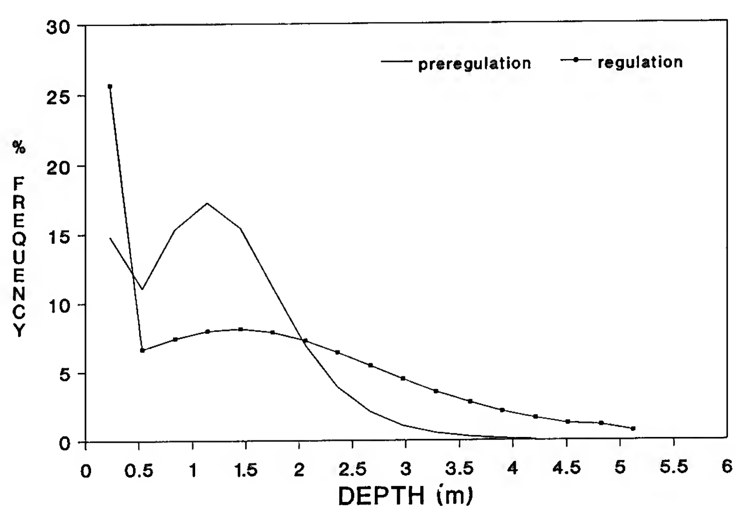


Fig. 5. Depth frequency distribution for the 50% exceedence flow for August, September, October, and November for the preregulated and regulated conditions.



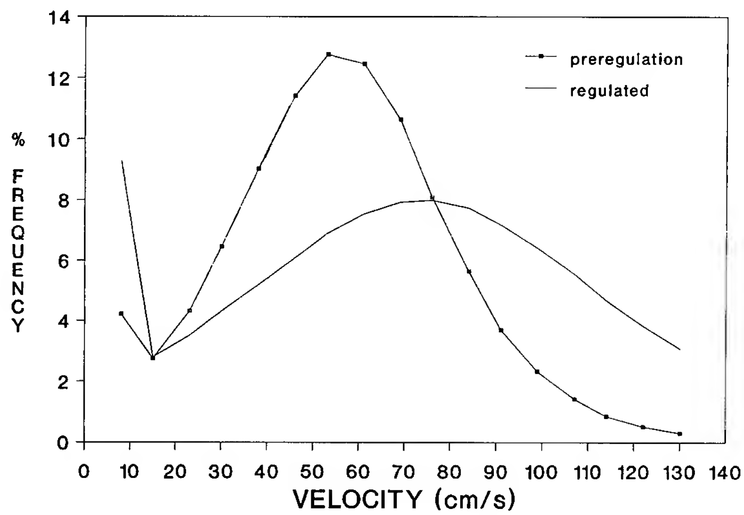


Fig. 6. Velocity frequency distribution for the 50% exceedence flow for August, September, October, and November for the preregulated and regulated conditions.

nonexistent in the preregulation condition compared with the regulated condition.

Velocity distribution also shifts under the regulated condition. Velocities between 0.30 and 0.76 m/s occurred most frequently under the preregulated condition (Fig. 6). Under the regulated condition velocities between 0.15 and 0.76 m/s occur less frequently, while velocities between 0.76 and 1.22 m/s occur more frequently.

Discussion

Annual Hydrograph

The simulated hydrographs for regulated and unregulated conditions describe a seasonal pattern of high and low flows. This pattern is evident at all three exceedence levels for both conditions. However, the shift in timing and magnitude of this pattern has ramifications for the endemic community that was adapted to the historic pattern. The importance of the high flow values is dependent on how frequent and at what time they encroach on the floodplain. Floodplain in this context is defined according to Junk et al. (1989) as "areas that are periodically inundated by the lateral overflow of rivers or lakes... ." They characterized this zone as having plant communities arranged along an elevation gradient according to flood tolerance. Junk et al. termed this area the aquatic-terrestrial transition zone (ATTZ). They explained that large rivers that periodically flood have communities with life history strategies adapted to regular inundation of this zone. In addition they postulated that in these systems most of the fish biomass was directly or indirectly dependent on the production in the ATTZ.

As the water surface approaches the ATTZ, the ability to predict the water surface elevation becomes difficult because of the increased roughness of the channel because of vegetation and debris. Water surface elevations were not determined for flows once they entered the floodplain; however, the flow at which this occurred was estimated. Inspection of the historic cross sections shows that flows in the range of 45,000–65,000 cfs result in water surface elevations high enough to inundate portions of this zone (U.S. Army Corps of Engineers 1991).

The preregulation simulated median flow for June was greater than 65,000 cfs, indicating that the ATTZ was inundated more than 50% of the time in the period of record. We conclude that preregulation inundation of the ATTZ was frequent enough to have an aquatic community whose life history strategies were adapted to take advantage of this inundation. Spawning by many species of fish inhabiting the Missouri River coincides with the preregulation timing of inundation of the ATTZ (Gardner and Stewart 1987; Pfleiger and Grace 1987).

Inundation of the ATTZ probably occurred during April and May but was of shorter duration and more sporadic. The largest flood on record occurred in April 1952 (Sveum 1988). The monthly exceedence values for April are lower than for June because the magnitudes of the runoff were probably smaller and of shorter duration than the runoff in June. The plains snowmelt and precipitation that is responsible for the March–April rise is usually

smaller and more variable than the mountain snowmelt that results in the June rise.

While flows under the regulation hydrograph may occasionally inundate the ATTZ (>50,000 cfs), inundation is much more likely to occur in August, and the duration is less than that of the preregulation inundation during June. The monthly values analyzed in this study are not sensitive enough to determine the frequency of daily inundation events that may have occurred under the regulated condition.

In contrast to the preregulation hydrograph, variation between the high and low monthly flows is reduced. Over time, the existing asynchrony of the inundation, along with the reduced variation in flow, will favor species that do not have life history strategies adapted to the annual inundation of the ATTZ. Also, species less well adapted to seasonal variation in stream flow will be favored over those that have adapted to this variation.

During the annual high flow events the specific depth and velocity distributions within the channel were probably not important factors in determining the community structure. Rather these events should have provided an annual influx of nutrients, provided a cue to spawning for certain species, and discouraged colonization by species whose life history strategies were adapted to more tranquil conditions.

Depth and Velocity Distributions

The shift in the depth and velocity distribution from the preregulation condition can be attributed to two factors. The channel cross sections have changed (degraded because of sediment being trapped in upstream reservoirs), and discharges have been increased to meet downstream navigation requirements. The combination of changing channel morphology and flow regime has caused a different pattern of available micro-habitats (depth–velocity combinations) than the native fish community was adapted to.

If the conclusions about the important factors defining fish community structure in small warmwater streams are applicable to large warmwater rivers, the shifts in the depth and velocity patterns for the Missouri River should, over time, reshape the community. The importance and pattern of habitat use by the fish community have not been identified for the Missouri River, but evidence indicates that changing depth and velocity patterns in late summer and fall have affected life history strategies. Changes in channel morphology and hence depth and velocity patterns created by drought conditions caused a shift in habitat use by shovelnose sturgeon (*Scaphirhynchus platorynchus*) in the channelized Missouri River (D. C. Latka, U.S. Army Corps of Engineers, unpublished data). Modde and Schmulbach (1977) attributed low ration biomass in the stomachs of shovelnose sturgeon in the present study reach to increasing water elevation and velocity from May through September. They speculated that prey organisms were more mobile and less concentrated than at other times of the year.

Implications for Restoration

Restoration of the native fish communities requires the availability of restoration criteria when projects are designed. Short lead time and uncertain funding levels do not allow for long-term, detailed studies to develop criteria.

While the mechanisms that determine the structure and persistence of the fish community in the Missouri River may not be fully understood, we believe the historic hydroperiod and habitat patterns played a major role. Therefore, we recommend that the historic depth and velocity patterns be the basis for the design of restoration projects for the native fish community. Designs for chutes and channels should include provisions for the establishment of an ATTZ that will be inundated in spring and early summer. Late summer and fall depth and velocity distributions should strive to mimic historic patterns. Alternative designs for restoration projects that include restoring habitat for the native fish community as a goal would benefit the community to the extent they mimic these historic patterns. The extent that alternative flow regimes mimic the inundation of the ATTZ and historic depth and velocity patterns will determine how beneficial they are to the endemic fish community.

This information should be developed for other reaches of the Missouri River to allow comparisons of historic habitat patterns between reaches and to provide better site-specific criteria for restoration designs. As better biological information becomes available we can develop hypotheses about the role seasonal patterns of flow and habitat played in structuring specific components of the fish community. Historic engineering data exist that can be used to model historic habitat. This approach provides the opportunity to use these data to develop criteria needed to engineer projects beneficial to the native fish community.

Acknowledgments

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Restoration Planning for an Abandoned Missouri River Chute

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Abstract. A Missouri River chute that was cutoff from the main channel by channelization was restored through the cooperative efforts of a number of agencies and disciplines. The objective was to restore the physical habitat to conditions similar to those that existed in the chute before channelization. This objective was somewhat constrained by the current Missouri River flow regime and a channel constriction caused by a bridge constructed over the chute. Water surface profile models (HEC-2) developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center were used to estimate flow characteristics of the chute with different inlet and chute width sizes. A chute width of approximately 23 m would be the probable ultimate size with a bridge constriction of 16 m. These dimensions would produce velocities considered necessary for maintaining this chute size and would be similar to those that occurred historically. An inlet width of approximately 55 m was determined to be the best size to ensure sediment transport and to minimize energy dissipation over the inlet. The inlet was constructed by cutting a notch in the existing chute closure structure and replacing existing rock with rock sizes sufficient to withstand expected velocities. Because of extensive sedimentation and vegetative encroachment, it was necessary to construct a 3-m-wide pilot channel throughout the chute to facilitate channel development. Three grade control structures were also constructed in the chute to guard against bed degradation and capture of the chute by the river. A monitoring program was initiated to document biological and physical changes that will occur following restoration.

Background

Bank stabilization and channelization work on the Missouri River was accomplished in three general phases. The River and Harbor Act of 1912 authorized a 6-ft-deep, 200-ft-wide navigation channel from Kansas City, Missouri, to the mouth. The project was extended upstream to Sioux City, Iowa, in 1927. It was increased to a 9-ft-deep, 300-ft-wide channel from Sioux City to the mouth by the River and Harbor Act of 1945.

Construction of the project was generally done by restricting the river to a single, stable channel with long smooth bends. Pile and stone dikes were constructed across the numerous secondary channels to direct the river into a single, narrower and deeper channel. In addition, new channel sections were cut to eliminate sharp bends, and closure structures were built to close chutes or diverted channels. Revetments were used to protect the concave bank from erosion after the desired alignment was achieved (Munger and Wixson 1972).

The project resulted in the loss of water surface area and the corresponding loss of physical habitat features such as chutes and sloughs. By the year 2003, it has been estimated that the natural channel area will be reduced from 121,408 ha to 45,326 ha because of the project (U.S. Army Corps of Engineers 1981). The river is now confined to a narrower, deeper channel with a fairly uniform cross section. Chutes and sloughs contained shallower and lower velocity water than the main channel. This type of habitat was an important component of the Missouri River ecosystem which served important requirements of native river fish, shorebirds, furbearers, and waterfowl (Funk and Robinson 1974).

Restoration Goal

The goal of the present project was to restore a chute or side channel to conditions similar to those present before channelization. This would involve reopening the upstream and downstream ends to the river and allowing the channel to develop its historic pattern and cross section. If the channel shape and pattern were restored in conjunction with a historic flow and sediment regime, physical habitat conditions such as depth and velocity distribution would be similar to what occurred historically. In theory, if physical habitat were restored, the historic functions of the chute would follow. These functions include spawning and rearing of various native fish species, feeding and nesting habitat of shorebirds, furbearer habitat, and waterfowl migratory habitat.

In reality, restoring the historic flow regime of these areas was not possible because of changes that have occurred in the Missouri River flow regime and the perched characteristic of some of these areas caused by main channel bed degradation. Given these constraints, the exact historic dimensions, and hence depth and velocity distributions of these areas, could not be attained. Therefore, the goal was to create physical habitat as similar to historic conditions as possible.

Evaluation of Potential Restoration Sites

Eight abandoned chutes or side channels from Sioux City, Iowa, to Omaha, Nebraska, were evaluated to determine the feasibility of fulfilling the objective described above (Fig. 1). This reach of the Missouri River was selected because it is under the jurisdiction of the PAPIO-MISSOURI River Natural Resources District, which was willing to serve as the local project sponsor with the U.S. Army Corps of Engineers. The natural resources district is a local tax-levying subdivision of state government that has natural resource management responsibilities in this sub-basin. Cost-sharing, real estate requirements, and operation and maintenance are the responsibility of the local sponsor under the authority used to carry out this restoration project (Section 1135, Water Resources Development Act of 1986). The following factors were considered in the feasibility evaluation: size of area to which fish and wildlife habitat could realistically be restored; existing degree of hydraulic connection; potential for adequate flow diversion without affecting navigation in the Missouri River; potential for allowing natural habitat features to develop (erosion/deposition zones, snag habitat); and potential for a self-sustaining channel to develop. The results of this evaluation are presented in Table 1.

A major consideration in determining the potential for developing a self-sustaining channel was whether the area was located on the outside of a river bend or on the inside of a bend. Considering the amount of river flow that could be realistically diverted, areas located along the outside of a river bend would have greater potential for sedimentation because of decreased gradient. Substantial

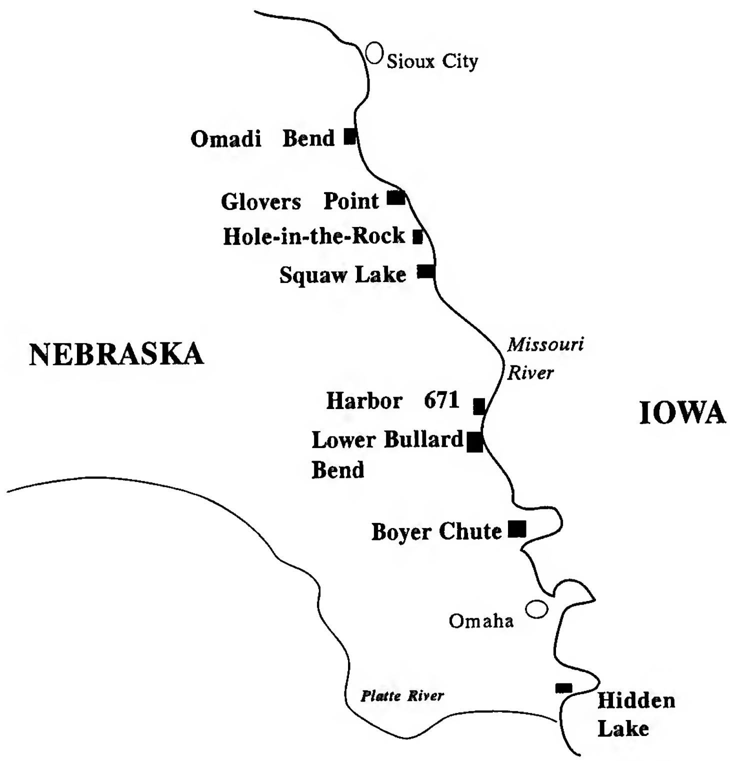


Fig. 1. Location of eight potential restoration sites.

maintenance efforts would probably be required to keep the area functional. In addition, the inlet or outlet would be subject to greater sedimentation if located on the side of the river opposite the navigation channel or in an area where the navigation channel crosses from one side of the river to the other (U.S. Army Corps of Engineers 1989). This would also result in considerable maintenance costs.

Restoration Site Description

Boyer Chute was selected for restoration because it contained a large area of adjacent land that could be restored to native terrestrial and wetland habitat, it had a good hydraulic connection to the river, significant flow could be diverted without affecting navigation, there were no constraints regarding aquatic habitat development,

Table 1. Evaluation of potential restoration sites.

	Evaluation factors				
Site	Area of habitat restoration (ha)	Existing degree of hydraulic connection	Flow diversion without affecting navigation	Allowance for habitat feature development	Development of self-sustaining channel
Omadi Bend	243	Poor	Good	Good	Moderate
Glovers Point	283	Moderate	Good	Good	Poor
Hole in the Rock	65	Good	Good	Good	Good
Squaw Lake	526	Moderate	Good	Good	Poor
Harbor 671	60	Good	Good	Poor	Good
Lower Bullard Bend	154	Moderate	Good	Good	Moderate
Boyer Chute	728	Good	Good	Good	Good
Hidden Lake	214	Moderate	Good	Good	Moderate

and it had good potential for developing a self-sustaining channel.

About 795 ha of land could potentially be restored to terrestrial and wetland habitat assuming the appropriate real estate was acquired. About 50 ha was historic chute habitat; the rest was agricultural land between the chute and the river and riparian vegetation along the chute and river (Fig. 2). At normal Missouri River summer–fall flows (25–40,000 cubic feet per second [cfs]; Fig. 3), the chute channel was composed of approximately 38 ha of developing riparian forest and 12 ha of backwater and associated unconsolidated shoreline. The chute is 4.8 km long and has a width that varies from 46 to 214 m between the high banks.

The chute is not as perched above the river as other upstream sites and therefore had a relatively good hydraulic connection. Main channel bed degradation in this vicinity has decreased

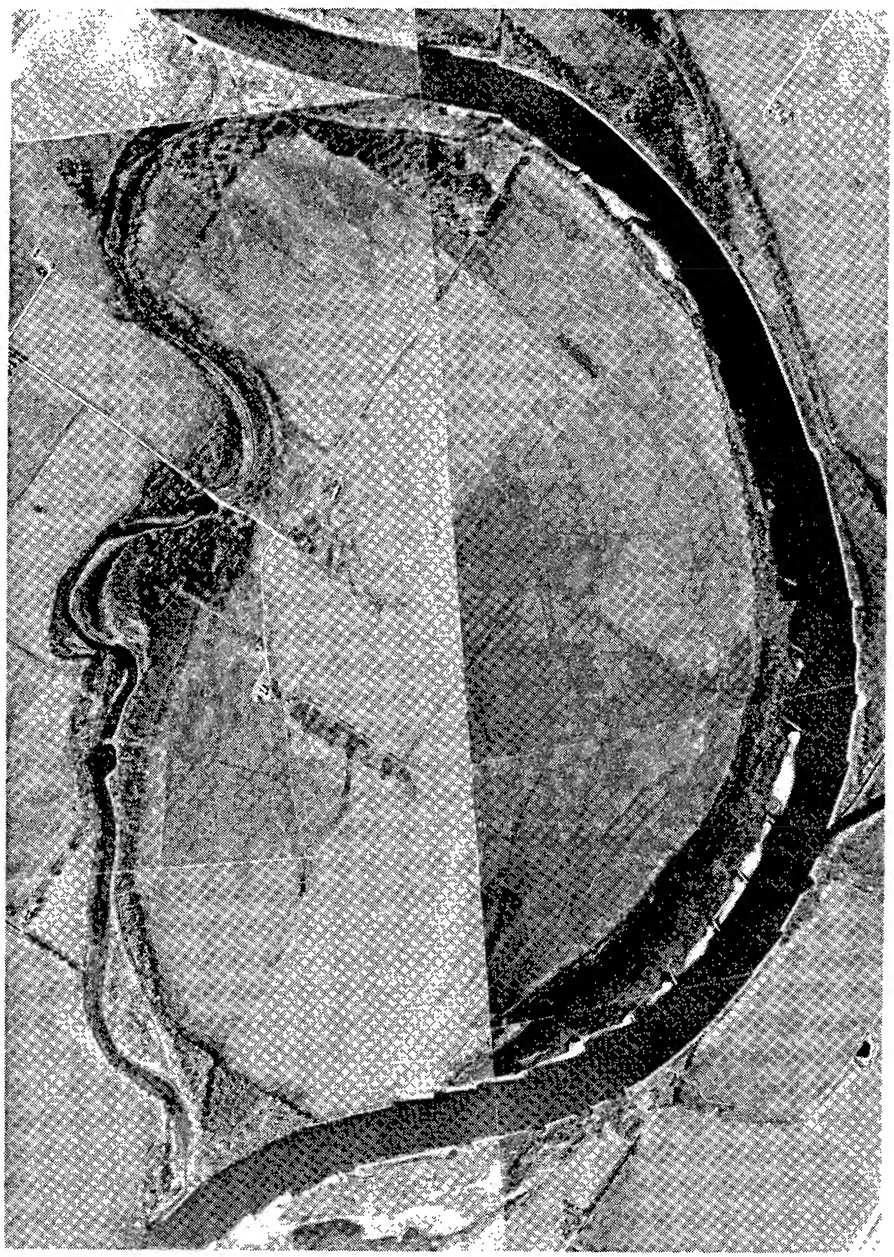


Fig. 2. Aerial photograph of Boyer Chute before restoration in March 1989. (Missouri River flow about 15,000 cfs).

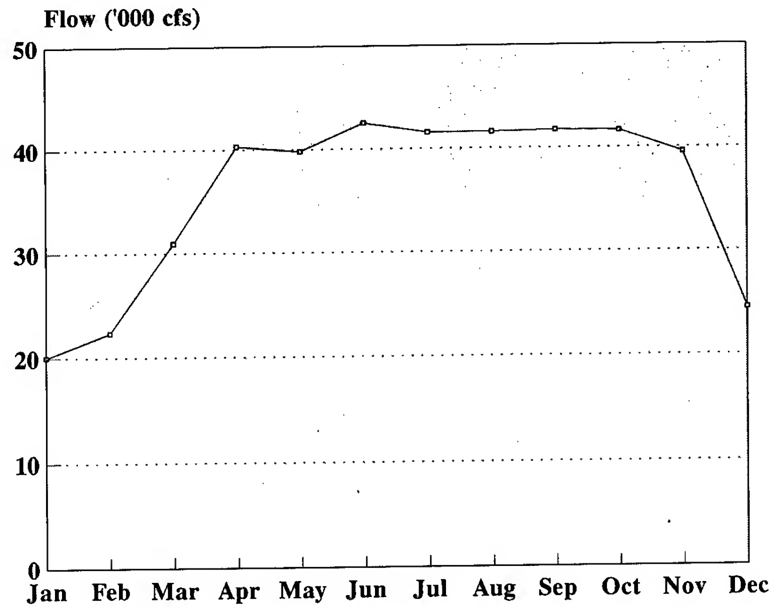


Fig. 3. Average monthly Missouri River flow at Omaha, Nebraska.

water surface elevations since 1936 by approximately 1.3 m compared to about 2.7 m at Sioux City, Iowa (U.S. Army Corps of Engineers 1991b). This was about the time Boyer Chute was cutoff from the river by a closure structure at its upstream end.

A road crossing was located a third of the way down the chute and consisted of culverts that were perched and did not effectively pass flow. Culverts were also installed through the upstream closure structure in an earlier attempt to connect the chute to the river. However, accumulated sediment on the chute side from past flood events normally restricted flow to less than 1 cfs. Seepage from the river did maintain a small intermittent rivulet in the upstream end at normal summer-fall flows. These factors caused considerable sedimentation and vegetative encroachment upstream of the road crossing.

Downstream of the road crossing the chute channel was relatively free of vegetation and consisted of backwater habitat because the outlet is open to the river at flows greater than 25,000 cfs. Therefore, about 67% of the chute's length had good hydraulic connection and good channel capacity, which reduced initial construction costs.

To analyze whether diverting flow through Boyer Chute would affect navigational service, water surface profiles were computed at various Missouri River flows for the river and the chute. The water surface profiles were computed using the HEC-2 computer model developed by the U.S. Army Corps of Engineers (1982) Hydrologic Engineering Center. The models were used to predict the amount of water that could be diverted to the chute during the navigation season and for a range of inlet sizes. Based on model output, a flow of about 1,700 cfs was considered the most that could be physically diverted to the chute at normal flows present during the summer–fall navigation season. This is because the backwater from the downstream end would limit the amount of flow through the chute. This diversion would cause a drop of about 0.1 m in Missouri River stage adjacent to the chute. Because depths in this area are well above the 2.7 m required for full service navigation, this diversion would have no effect on navigation.

The natural resources district would acquire 795 ha of adjacent land to allow the entire area to be restored as a site within its Missouri River Corridor Project. The natural resources district goal is to utilize the restored chute as the focus for a larger aquatic and terrestrial restoration area. Site usage will include educational and research opportunities, as well as limited public access. Following restoration of the entire area, the U.S. Fish and Wildlife Service agreed to operate and maintain the site as a National Wildlife Refuge. Development along the chute will be restricted so that erosion, deposition, and snag habitat will be allowed to develop naturally.

The chute cuts across an inside bend of the Missouri River, which causes an increase in gradient. Therefore, there is good potential for develop-

ing a self-sustaining channel by producing velocities sufficient to prevent excessive channel aggradation. In addition, the inlet and outlet are located in the navigation channel, where velocities are sufficient to prevent sedimentation.

Methods

Development of Objectives

Planning for this particular project required considerable coordination between the natural resources district, U.S. Fish and Wildlife Service, Nebraska Game and Parks Commission, and U.S. Army Corps of Engineers. The U.S. Army Corps of Engineers provided the funding mechanism, restoration design, and 75% of the initial construction costs. The natural resources district provided 25% of the initial cost and had the responsibility of securing all required lands and right-of-ways and of operating and maintaining the project after construction. The Nebraska Game and Parks Commission provided expertise on the status of local resources, which guided the development of restoration goals and design concepts.

The goal of the project was to restore, to the extent feasible, the physical habitat that occurred in Boyer Chute before closure in 1937. River maps from 1890 and 1923 were used to determine the historic condition of the chute. It was necessary for the biologists to define specific physical habitat objectives of the project considering constraints imposed by the existing Missouri River flow regime and bridge construction over the chute. Hydraulic engineers designed the project to satisfy these objectives. Therefore, considerable interaction between these disciplines occurred throughout the planning phase of this project.

Sediment Analysis

A major consideration of attempting this type of restoration was designing a self-sustaining channel in the presence of high sediment loads and a highly variable flow regime. Depth-integrated sediment data collected from 1984 to 1988 at Omaha were analyzed to determine the change in sediment concentration at various depths in the water column. This was done to determine at what depth heavy sediments could be precluded from entering the chute, thereby reducing operation and maintenance costs.

Hydraulic Analysis

An HEC-2 model was set up and calibrated for the Missouri River in this area to develop stage versus discharge (rating) curves at the chute inlet and outlet. These rating curves were used with a chute HEC-2 model to determine the flow and velocities through the chute with various chute inlet and channel widths. Chute channel widths of 23, 46, and 92 m (except at the bridge), with trapezoidal cross sections and inlet widths, ranging from 153 m to the same channel widths were modeled to determine the best design dimensions.

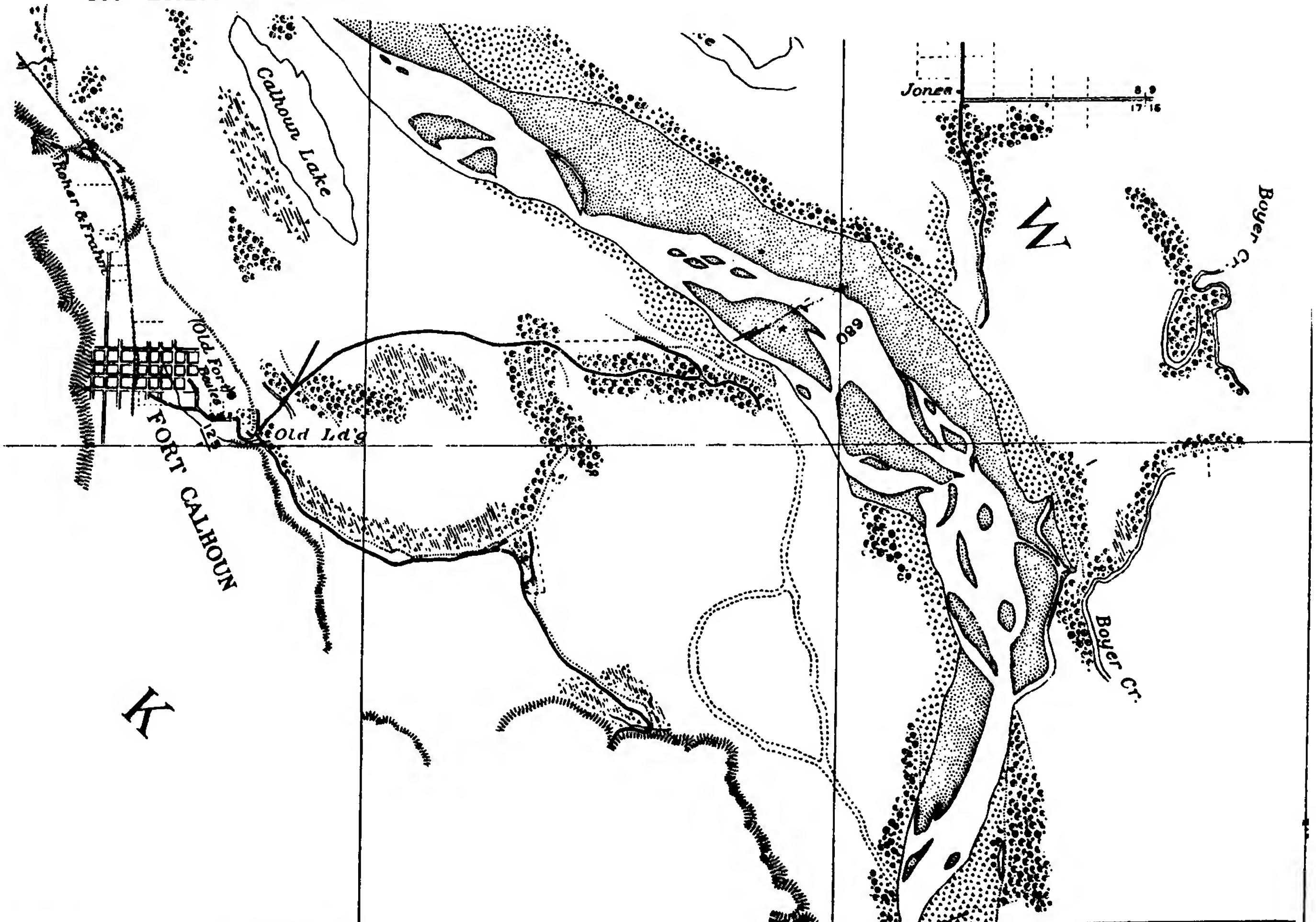
The analysis included modifying the HEC-2 chute model to include a channel constriction of 16 m caused by bridge construction to replace the existing culvert crossing. This was also a major consideration in planning this project and somewhat constrained the restoration goal. However, a bridge was necessary to provide heavy machinery access to the area so that restoration of terrestrial habitat could be accomplished. A 16-m constriction was determined to be the maximum span that could be constructed because of the cost.

From the hydraulic analysis, rating curves were established for each chute width to determine the relationship between Missouri River flow and chute flow. Because velocities are critical design considerations for fishery objectives and channel stability, the models for the various widths were adapted to determine average velocities over a range of potential channel roughness (Manning's "n") values with various flows. Maximum average velocitities in the channel downstream from the bridge, upstream from the bridge, and at the bridge were determined.

Monitoring

The monitoring plan will consist of evaluating physical and biological attributes of the project. Physical habitat evaluation is required to compare hydrologic and sediment performance with modeling projections. This will be the basis for determining whether the project should be modified to accomplish the objectives of the project.

Ten permanent cross-section ranges were established evenly throughout the chute and will be surveyed annually during the first 5 years of operation and in the 10th year. Velocity measurements will be obtained at 3 of the 10 cross sections twice a year in the first 5 years and in the 10th year. Less frequent surveying may be used if the channel stabilizes earlier. These data will be used


Calhoun Lake
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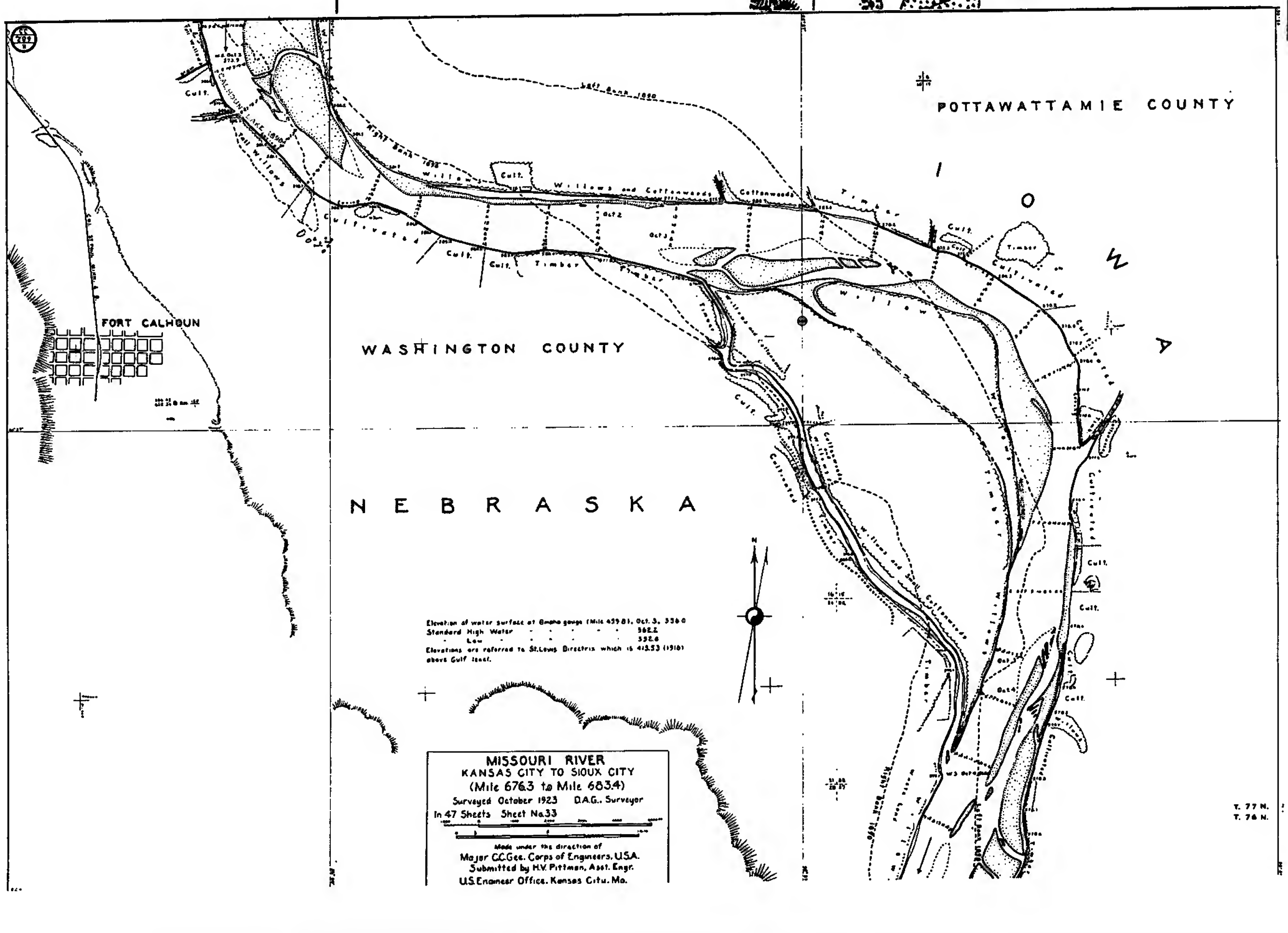
POTTAWATTAMIE COUNTY
I O W A
FORT CALHOUN
WASHINGTON COUNTY
N E B R A S K A
Elevation of water surface at Omaha gauge (Mile 459.8), Oct. 3, 556.0
Standard High Water 562.2
Low 552.6
Elevations are referred to St.Louis Directrix which is 413.53 (1910) above Gulf level.
MISSOURI RIVER
KANSAS CITY TO SIOUX CITY
(Mile 676.3 to Mile 683.4)
Surveyed October 1923 D.A.G., Surveyor
In 47 Sheets Sheet No.33
Made under the direction of
Major C.C.Gee, Corps of Engineers, U.S.A.
Submitted by H.V. Pittman, Asst. Engr.
U.S.Engineer Office, Kansas City, Mo.

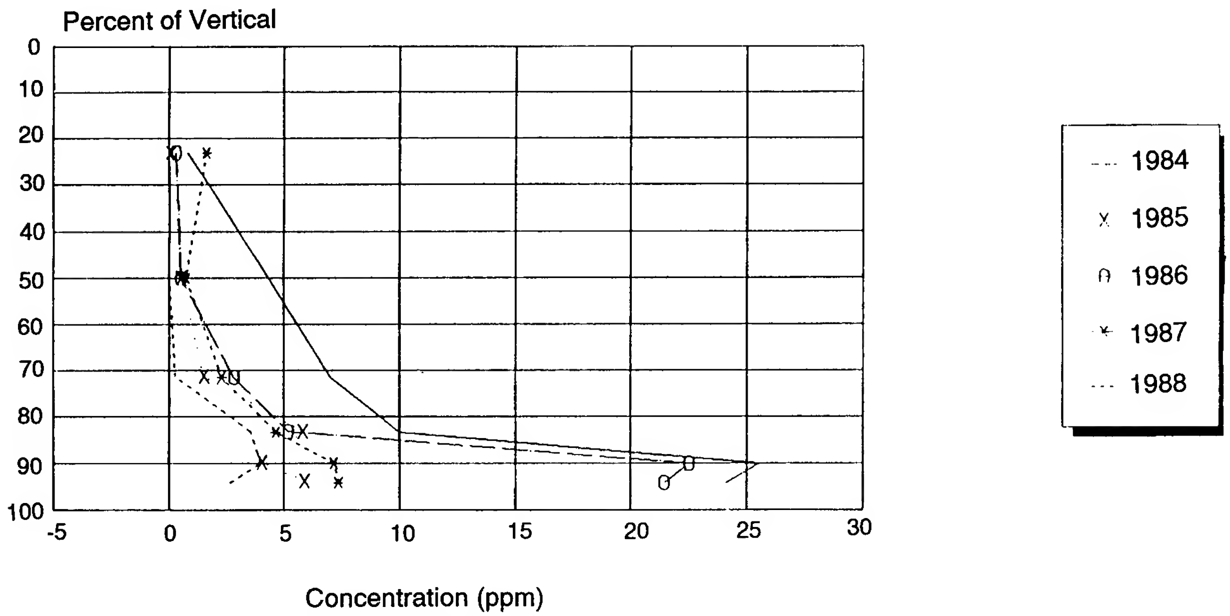

Fig. 5. Sediment concentration (0.420–0.297 mm) of the Missouri River at Omaha, Nebraska. (Reprinted from U.S. Army Corps of Engineers 1989.)

Table 2. Comparison of average chute discharges and velocities at various chute widths.

Missouri River discharge (cfs)	Chute discharge (cfs)				Chute velocities (m/s)			
	3-m	23-m	46-m	92-m	3-m	23-m	46-m	92-m
Downstream of bridge								
20,000	35	100	150	250	0.40–0.95	0.27–0.37	0.27–0.30	0.21–0.27
31,000	350	750	1,250	1,600	0.82–0.88	0.61–0.67	0.52–0.61	0.37–0.46
40,000	800	1,450	2,300	2,850	0.95–0.98	0.73–0.76	0.64–0.73	0.46–0.52
50,000	1,400	2,300	3,500	4,200	1.16–1.28	0.92–0.98	0.79–0.88	0.52–0.61
60,000	2,300	3,400	4,800	5,500	1.22–1.56	1.07–1.19	0.92–1.01	0.58–0.67
70,000	3,600	4,500	6,100	6,800	1.25–1.74	1.10–1.31	1.01–1.13	0.67–0.73
80,000	5,000	6,500	8,200	9,200	1.34–1.89	1.31–1.59	1.16–1.31	0.79–0.85
90,000	6,900	8,500	11,300	14,250	1.43-2.01	1.43-1.71	1.34-1.49	0.98-1.07
Upstream of bridge								
20,000	35	100	150	250	0.27–0.52	0.21–0.31	0.21–0.27	0.15–0.24
31,000	350	750	1,250	1,600	0.40–0.61	0.46–0.64	0.49–0.64	0.34–0.37
40,000	800	1,450	2,300	2,850	0.46–0.76	0.52–0.76	0.58–0.76	0.40–0.43
50,000	1,400	2,300	3,500	4,200	0.58–0.85	0.58–0.88	0.64–0.88	0.46–0.49
60,000	2,300	3,400	4,800	5,500	0.67–1.01	0.95–1.01	0.73–0.98	0.49–0.55
70,000	3,600	4,500	6,100	6,800	0.85–1.16	0.73–1.07	0.82–1.04	0.55–0.58
80,000	5,000	6,500	8,200	9,200	1.01–1.40	0.85–1.28	0.95–1.19	0.64–0.67
90,000	6,900	8,500	11,300	14,250	1.19–1.65	0.95–1.40	1.10–1.46	0.88–0.98
At bridge								
20,000	35	100	150	250	0.09–0.12	0.31–0.43	0.49–0.67	0.73–1.01
31,000	350	750	1,250	1,600	0.24–0.31	0.67–0.92	1.13–1.62	1.68–2.44
40,000	800	1,450	2,300	2,850	0.40–0.49	0.82–1.10	1.43–1.92	2.07–2.81
50,000	1,400	2,300	3,500	4,200	0.58–0.70	1.04–1.34	1.71–2.23	2.41–3.20
60,000	2,300	3,400	4,800	5,500	0.64–0.92	1.16–1.59	1.86–2.56	2.68–3.54
70,000	3,600	4,500	6,100	6,800	0.64–1.04	1.07–1.83	1.86–2.81	2.96–3.84
80,000	5,000	6,500	8,200	9,200	0.64–1.04	0.88–1.86	1.43–3.32	3.02–4.97
90,000	6,900	8,500	11,300	14,250	0.64–1.04	0.82–1.56	1.13–2.56	1.98–3.32

to compare the cross sections with each other and to evaluate if project objectives are met.

Aquatic invertebrates and the fish community were sampled at four stations in the chute and three stations in the river before construction. Sampling will be conducted for several years following construction. Electrofishing, gillnetting, seining, and trapnetting will be used seasonally, and larval nets will be used in late spring and early summer. Benthic and aufwuchs invertebrate sampling will also be conducted seasonally. Brunsing (1993) provided a detailed description of the methods and materials employed in sampling these communities before construction.

Results

Objectives

Maps of the Boyer Chute area in 1890 and 1923 indicate that the main river channel was unconstrained, and its shape and direction changed considerably, depending on flow regime (Fig. 4). However, at both times there was a fairly well-defined chute that cut across this particular bend. This probably occurred as a result of high flows exceeding channel capacity and developing a higher gradient passage through the bend. The flow regime of the chute was characterized by high spring flows, lower summer flows, and no flow in the winter.

Because the maps do not include elevations of the chute channel, it was not possible to precisely identify the flow regime and hence depth and velocities that occurred within the chute. It was decided to restore summer–fall depths and velocities in the chute similar to what historically occurred in the Missouri River. Latka et al. (1993) found that historically in late summer and fall, 98% of the Missouri River channel was less than 3 m deep, and velocities between 0.3 and 0.76 m/s occurred most frequently. These physical habitat objectives guided the development of the restoration design in conjunction with other considerations described below.

Sediment Analysis

Results of the sediment analysis showed a general decline in the concentration of larger grain-size fractions in the upper water column of the Missouri River (Fig. 5). This is expected as the river bed material becomes coarser because of channelization and erosion control. Therefore, a critical design consideration was to divert water from the upper water column and to maintain sufficient velocity through the chute to carry the expected sediment load.

Hydraulic Analysis

The results of the hydraulic analysis showed little or no effect on the chute water surface profile for inlet widths ranging from 153 m to the same width of the channel being modeled. The reason for no effect is that the backwater effect from the downstream end controls flow through the inlet, rather than the size of the inlet.

Table 2 presents the range of expected flows and velocities for various restored channel widths. Based on these results, a natural channel resembling or slightly wider than 23 m was considered the probable ultimate channel size for the 16-m bridge opening. This size channel would maintain velocities adequate to carry the expected sediment load without causing bed degradation over a wide range of flows. The channel would probably not erode and maintain a 92-m width, as the velocities would be low enough to allow aggradation to occur.

Maximum average velocity would not occur at the same cross section over the range of flows modeled, which indicates that some natural meandering would occur. A meandering channel would result in a diversity of habitat features, which is considered important to the native river community.

A 23–31-m wide channel, at normal summer–fall flows (25,000–40,000 cfs), would also produce velocities that are within the range of what occurred under historic river conditions in summer and fall (0.3–0.76 m/s). Sustained swimming speed of most fish is generally less than 1.2 m/s, and darting speeds range from 1.2 to 3.0 m/s. Velocities should be kept well below the darting speed for general passage (U.S. Army Corps of Engineers 1991a). Average velocities at the bridge opening would be less than 1.2 m/s for normal summer–fall flows and less than 1.9 m/s for river flows up to 90,000 cfs. If the channel eroded laterally to as much as 46 m in width, velocities would be within an acceptable range except at high flows at the bridge opening. Depths produced at this channel width and at normal summer–fall flows would be less than 3 m, given the trapezoidal cross sections used in the hydraulic analysis.

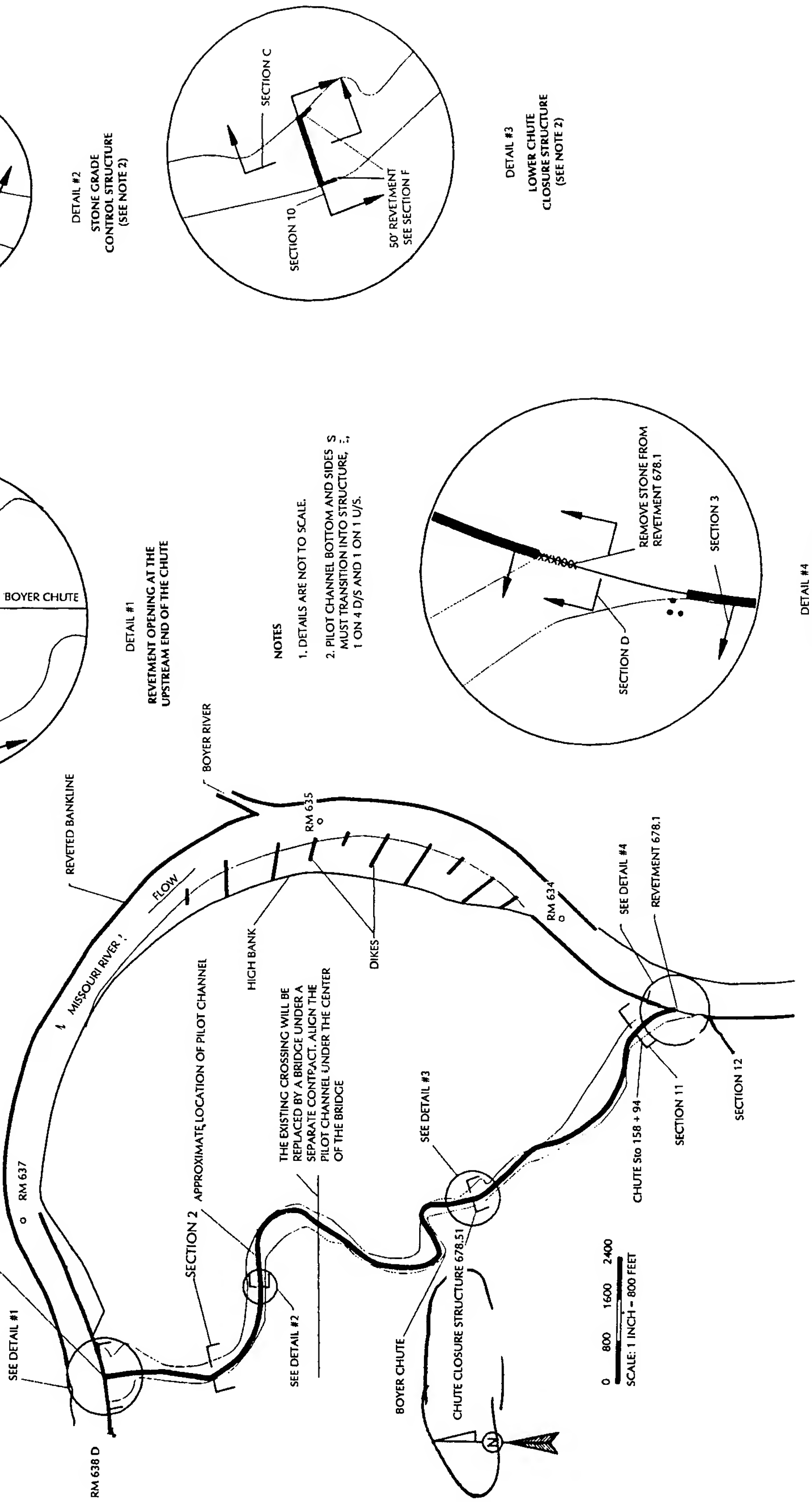

Fig. 6. General plan view of Boyer Chute restoration project.

Restoration Design

The following restoration design (Fig. 6) was based on the probable ultimate channel width of 23–31 m. As discussed previously, a sensitivity analysis was conducted on inlet widths ranging from 153 m to the same width as the design channel. This analysis revealed that little difference in flow resulted from changing the inlet width. To ensure sediment transport and to minimize energy dissipation over the inlet, velocities through the inlet should be similar to those in the chute channel. A 55-m-wide notch in the closure revetment was selected as the size that best met this criterion. A 92-m-wide notch will be constructed and 37 m refilled with larger stone to achieve the 55-m width. This will allow future enlargement up to 92 m if necessary. There is some uncertainty regarding how much flow will actually be diverted into the chute, the width of the ultimate channel, and whether the chute will be stable without aggrading or degrading. Therefore, it was considered essential that design of the inlet structure allow for modification.

Because of sedimentation and vegetative encroachment in the upper end, it was considered necessary to construct a pilot channel to facilitate channel development. A 3-m-wide pilot channel would produce maximum velocity just upstream from the transition from pilot channel to outlet. This would be more than adequate to initiate lateral erosion of the channel. As the downstream channel capacity increases, flows would increase, and the point of lateral erosion would progress upstream through the chute.

The width of the outlet revetment notch is not as critical because the Missouri River would normally provide control of flow through the outlet. In the event that tailwater control would be lost on the river (e.g., ice jam on the river between the inlet and outlet), the width of the outlet would need to be wide enough to reduce velocities over the structure but narrow enough to prevent excessive channel widening from the outlet to the bridge. To balance these concerns, an outlet width of 40 m was selected.

To guard against head cutting and the possibility of the chute ultimately capturing the main flow of the river, three stone grade control structures will be constructed. One of these structures will be constructed by lowering an existing closure structure located about 1.6 km upstream of the outlet, another will be constructed about 0.8 km upstream of the bridge, and the third will be constructed at the outlet. Each structure would maintain the backwater on the next upstream structure, while the Missouri River would maintain the backwater on the downstream structure.

Monitoring

The following discussion is taken entirely from Brunsing (1993), who conducted the preconstruction sampling during 1991 and early 1992. Preconstruction sampling of the larval fish community in Boyer Chute indicated that catostomids (suckers) and cyprinids (minnows) were the most abundant taxa collected. Catostomids collected were primarily river carpsuckers (*Carpiodes carpio*), although this may be a result of sampling after other sucker larvae were recruited into the juvenile population. Minnows included emerald shiners (*Notropis atherinoides,*) red shiners (*Cyprinella lutrensis*), sand shiners (*Notropis stramineus*), and silver chubs (*Macrhybopsis storeriana*). Small numbers of *Lepomis* spp. were also collected in the chute but not in the adjacent Missouri River. Freshwater drum (*Aplodinotus grunniens*) and gizzard shad (*Dorosoma cepedianum*) larvae were collected in the Missouri River but not in the chute during 1991.

Adult fish in Boyer Chute were dominated by centrarchids (sunfish), which are adapted to lentic conditions. Largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), white crappie (*P. annularis*), and bluegill (*Lepomis macrochirus*) were only sampled in the chute. River carpsucker, smallmouth buffalo (*Ictiobus bubalus*), bigmouth buffalo (*I. cyprinellus*), shortnose gar (*Lepisosteus platostomus*), and gizzard shad were sampled in the chute and the river but were more abundant in the chute. Blue sucker (*Cycleptus elongatus*), shovelnose sturgeon (*Scaphirhynchus platorynchus*), and flathead catfish (*Pylodictis olivaris*) are examples of species adapted to lotic conditions, which were only found in the river.

The aufwuchs community in the chute was less diverse than that of the Missouri River and was dominated by large numbers of one genus of Chironomidae (*Glyptotendipes* spp.). Caddis flies, from the family Hydropsychidae, were the dominant species in the Missouri River and were considerably more abundant than in the chute. Mayflies were also much more abundant in the river than in the chute. Conversely, the benthos of the chute was considerably more diverse and abundant than in the river and included oligochaetes,

chironomids, and *Hexagenia* spp. These results indicate the lentic habitat conditions that existed in the chute before restoration.

Status

The project was constructed during winter 1992 and spring 1993 and experienced relative high flows during the spring months. Post-project monitoring began in May 1993, and observations indicate the presence of shovelnose sturgeon, a species adapted to lotic conditions. Erosion zones, deposition zones, and snag habitats are also forming.

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Missouri River Master Manual Review and Update Impact Assessment Methodology

by

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Abstract. The Missouri River Master Water Control Manual (Master Manual) presents the basic water control plan and objectives for the integrated operation of the six mainstem reservoirs in conjunction with the downstream projects. The Master Manual was first published in December 1960, with minor revisions in 1973, 1975, and 1979. Use of the reservoirs and river flows resulting from the mainstem system and its operation have changed since the first Master Manual was written. Also, the U.S. Army Corps of Engineers is now more aware of the effect that project operation can have on the environmental resources found along the mainstem system. The Missouri River basin is currently experiencing a drought that began in 1987 and has affected project uses and environmental resources. Effects associated with the current drought prompted numerous inquiries from the public, state and federal agencies, and congressional interests regarding the operation of the mainstem system. In response, the U.S. Army Corps of Engineers initiated a review of the current Master Manual in November 1989. A major element of the review was an impact assessment of the existing plan and a number of alternate water control plans. The objective was to quantify the effects associated with these water control plans. It was not apparent that all of the effects could be quantified, especially those associated with the environmental resources found along the mainstem system. An impact assessment methodology was formulated and successfully employed that reasonably identifies the level of effect associated with the various water control plans.

The U.S. Army Corps of Engineers began the construction of what was to become a system of six dams on the Missouri River mainstem in 1933. Fort Peck Dam, near Glasgow, Montana, was constructed as a Works Progress Administration project, and it was completed in 1940. Following the drought of the 1930's and several major floods in the early 1940's, Congress authorized the construction of the Pick–Sloan Plan in 1944. This authorization resulted in the construction of five more mainstem dams and the incorporation of Fort Peck Dam into an integrated system of six dams. Construction of the additional five dams began in 1946 with the construction of Garrison Dam near Garrison, North Dakota, and Fort Randall Dam near Lake Andes, South Dakota.

Over the next 13 years, construction of the remaining three dams was begun. Oahe Dam (near Pierre, South Dakota) construction was initiated in 1948, Gavins Point Dam (near Yankton, South Dakota) construction began in 1952, and Big Bend Dam (near Chamberlain, South Dakota) construction began in 1959. Mainstem dam construction was completed in 1964, and the system was first filled to normal operating levels in 1967.

Inflow to the mainstem system averaged near normal levels over the next 20 years. Typically a dry year or two was followed by a wet year, and

the levels of the mainstem reservoirs and the flows in the river reaches were about the same year after year. Those adjacent to the reservoirs and those relying on the flows downstream from each of the dams became dependent on the resulting normal reservoir levels and river flows during this period.

Development prospered adjacent to the reservoirs and river reaches. Recreation facilities were constructed adjacent to the reservoirs and river reaches. Many communities and, recently, rural water districts tapped the better quality water in the reservoirs by constructing intakes. Farmers extended pipes into the reservoirs and river reaches to provide irrigation water. Numerous power plants were constructed that rely on the abundant river flows for once-through cooling water.

The upper basin states in which the reservoirs are located have taken advantage of the resulting new water resources to provide enhanced recreation opportunities. State game and fish agencies have taken advantage of these large, deep reservoirs by establishing cold and coolwater fish populations. Coldwater fish species have been introduced to Fort Peck Lake, Lake Sakakawea (behind Garrison Dam), and Lake Oahe. There is also a coldwater fishery in the river reaches below Fort Peck and Garrison dams. These are some of the many fish and wildlife resource benefits that have resulted from the construction of the mainstem system of reservoirs.

Normal operations began in 1967. Spring plains snowmelt and subsequent mountain snowpack runoff are stored in the mainstem system reservoirs. This virtually eliminates the spring and early summer floods that occurred before the construction of the dams. These inflows normally result in the filling of the annual flood control and multiple use zone that is set aside for such inflows. This storage is primarily in the upper three reservoirs, as they contain about 88% of the mainstem system storage. Releases from the various dams are made to evacuate the water stored in this flood control storage zone and to support the downstream river uses. Because navigation has the highest flow requirements of all of the downstream uses, release criteria are tied in with the level of navigation service in terms of allowable loading and season length. Normal service to navigation is referred to as full service, and the barges are loaded such that they have an 8.5-foot draft. Flow requirements for the other uses are met by the navigation full-service releases. Power plants and other water supply needs are met by these releases. Recreational use of the lower river responded to these releases with the construction of numerous marinas, boat ramps, and other facilities.

Water levels in the upper three mainstem reservoirs dropped dramatically in 1988 when a second, consecutive dry year occurred. The 1988 mainstem system inflow was the fourth lowest on record dating back to 1898. This drought continues, as 1992 was the sixth consecutive year of drought in the upper Missouri River basin.

Reduced Missouri River mainstem system inflows above Sioux City resulted in an unprecedented reduction in water levels at the upper three mainstem reservoirs. Because the inflows were not adequate to raise the water levels back into the annual flood control and multiple use zone, water was withdrawn from the next lower storage zone, the carryover multiple use zone. Beginning in 1988, the low water levels hindered recreational access, caused problems for some water intakes, and disrupted fishery management plans on the reservoirs.

The water control plan for releases from Gavins Point Dam (system releases) is presented in the Missouri River Master Water Control Manual (Master Manual). The water control plan outlines conservation measures that reduce the rate of release of water from the system during drought periods as water in the carryover multiple use zone diminishes. At the end of the 1988 navigation season, system releases were reduced from those in previous winters to conserve water. This reduction—in conjunction with ice bridging—resulted in problems for several downstream water supply intakes. In addition, the 1989 navigation season was shortened from its normal 8-month season (April–November), and system releases were reduced, which resulted in lighter loading of the barges.

A variety of other issues surfaced not related to the current drought. Concerns were expressed on the need for even lower releases from the system during periods of flooding along the lower river. Special operations began for the endangered least tern and threatened piping plover following consultation with the U.S. Fish and Wildlife Service under Section 7 of the Endangered Species Act. In recent years, releases in spring were increased every third day to the highest levels predicted to be required for navigation during summer. This

resulted in higher nesting by least terns and piping plovers, with the objective of minimizing nest flooding. This would increase the number of birds fledged above current levels, toward the goal identified by the U.S. Fish and Wildlife Service. If the nests are not destroyed by navigational releases at any time during the summer, the hope is that the number of birds fledged may increase. This practice has made it even more difficult to minimize spring flooding below Gavins Point Dam and to serve navigation in summer if predictions of required summer releases are too low. Therefore, concerns regarding system operation began to surface throughout the basin as the drought continued.

In response to public concerns over lower reservoir levels and river flows, the U.S. Army Corps of Engineers embarked on a review of the existing water control plan contained in the Master Manual in November 1989. This study has come to be named the Missouri River Master Water Control Manual Review and Update (Review and Update).

The Review and Update is being conducted in a two-phase approach. Phase 1 consisted of a cursory review of the national economic effects of the existing water control plan and an array of alternatives to provide some guidance as to the merit of further study and the direction of future formulation of alternatives. A Phase 1 report was circulated to the public in May 1990, and public meetings were held in June 1990 to receive public input into the process at that point. Public input indicated there was a strong desire to continue to carry a wide array of alternatives into Phase 2.

Phase 2 was initiated in July 1990 with the preparation of the plan of study and some data acquisition efforts. Early in the Phase 2 effort the decision was made that an environmental impact statement should also be prepared as part of the Review and Update. The need to prepare an environmental impact statement was based on the fact that any change in the water control plan probably would be classified as a major federal action with a significant effect on the human environment. Therefore, an environmental impact statement would be required under the National Environmental Policy Act. The required scoping meetings were held at eight sites from Helena, Montana, to Memphis, Tennessee, over a 2-week period in October 1990.

The objectives of this paper are (1) to provide an overview of the impact assessment methodology, (2) to summarize the associated coordination process used to develop and implement the methodology, (3) to present some details on the specific approach for the various resources and uses modeled, and (4) to present results of the analysis for several water control plans. Each of these topics is discussed separately.

Impact Assessment Methodology Overview

The impact assessment methodology employed for the Review and Update had to be designed to fulfill two requirements. First, the methodology needed to be efficient enough to be run on a very large array of alternatives. The information provided on these alternatives needed to be of sufficient detail to assist with a basic understanding of overall trends within the full array of alternatives. Second, the output data needed to be of sufficient detail to provide an in-depth understanding of a limited array of alternatives chosen for detailed presentation in a draft environmental impact statement for public review.

The foundation of any analysis of the effects of a change in the water control plan and subsequent operation of the mainstem system is a hydrologic simulation model. An existing model, the Long Range Study Model (U.S. Army Corps of Engineers 1993a), or LRS Model, was modified to provide the needed hydrologic data. The LRS Model is a time-series computer model that provides reservoir and river data using the historic flows into the Missouri River mainstem for a specified period of analysis, assuming that the system of mainstem dams was in place for the entire period. Output from the LRS Model provides insight on what could have happened under the various water control plans had the system of dams been in place and fully operational for the period being modeled.

The hydrologic period of record on the Missouri River spans from 1898 to the present. The full 93-year period of record from March 1898 to February 1991 was selected as the period to analyze the effects of using the existing and alternative water control plans. Use of the LRS Model over this period assumes that the system was fully operational in 1898. Also, the historic inflows were adjusted to the 1990 level of depletions, or consumptive withdrawals.

The LRS Model provides end-of-month reservoir pool elevations at the six mainstem reservoirs

and average monthly river flows for the 1,116 months in the period of record being simulated. This approach is in contrast to a stochastic analysis based on probabilities, that is, occurrence of a 100-year or some other frequency event. Also, the LRS Model is a descriptive model that identifies the effects of a set of operating criteria on reservoir water levels or river flows. These data can then be used in other descriptive models to determine the corresponding effects on the various resources and uses relying on water in the reservoirs and river flows. This is in contrast to the use of a prescriptive model that identifies a plan that optimizes a specific output such as total economic benefits in terms of dollars or wetland habitat in terms of acres.

Many resources and uses rely on the water stored in the Missouri River mainstem reservoirs and the flows in the river reaches. To analyze effects of the existing water control plan and its alternatives on these resources and uses, the relationship between the value of a resource or use being analyzed and the corresponding reservoir water surface elevation or river flow had to be developed. Resource- and use-specific value functions were developed to relate the resource or use value to a reservoir elevation or a river flow, whichever is applicable. Value functions were developed for five use categories—flood control, hydropower, recreation, water supply, and navigation—and for five resource categories—reservoir aquatics, riverine aquatics, wetland and riparian habitat, tern and plover habitat, and historic properties. Development of the individual value functions will be discussed later; however, the economic values for the uses were in terms of dollars, and the environmental values for the resources were expressed in a variety of units appropriate for each particular resource.

Implementation of the value function approach required the modification of existing computer models from various sources or the development of new computer models specifically for this study by many different participants from various U.S. Army Corps of Engineers offices and consultants. These models were compiled into two independent models, an economic impacts model and an environmental impacts model (U.S. Army Corps of Engineers 1993b). Computerization of the impacts models was essential to allow an efficient and detailed impact assessment process.

The impact models apply output data from the LRS Model on a monthly or other appropriate time-step basis to the value functions. The impact models store the resulting resource or use value on the appropriate time-step basis. Therefore, up to 1,116 values are computed for each value function being used. These data can then be summarized in any way determined to be appropriate. For example, an average annual value can be computed or the minimum monthly value identified. One can follow the impacts as they occur on a month-by-month or year-by-year basis or look at the individual or consolidated values. The number of values computed and the way they were used varied from resource to resource. In the case of economic impacts, generally the average annual value was used; however, the monthly values were available for those wanting to examine what happened at various times during the 93-year period of analysis.

In river reaches that are subject to hydropeaking, some value functions were based on river stage instead of flow because a particular flow results in a maximum and a minimum stage at a given location owing to the daily peaking pattern. In these cases, LRS Model monthly flow simulations are translated into a maximum and a minimum stage using stage-discharge relationships (rating curves) developed using output from the application of the existing U.S. Army Corps of Engineers dynamic-flow model, Unet (Barkau 1992). This model applies a typical peaking pattern for a given range of average monthly flows and predicts the maximum and minimum stage for each flow at various locations downstream.

Coordination

One of the first steps made by the states at the outset of the Review and Update was to form an organization referred to as the Governors' Oversight Committee to monitor U.S. Army Corps of Engineers progress on the study. Ultimately, the Missouri River Basin Association reinstituted its role in basin planning and obviated the need for the Oversight Committee. As the Review and Update progressed, it became apparent to the Missouri River Basin Association Board of Directors that it needed to involve technical staff in the process. The U.S. Army Corps of Engineers also recognized the need to obtain the input of known state and federal technical experts in the basin as it prepared the plan of study for Phase 2. Therefore, the U.S. Army Corps of Engineers agreed to work with a set of four technical subcommittees,

organized by the Missouri River Basin Association, throughout the study process. Two federal agencies—the U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency—participated in technical subcommittee meetings. Also, to cover some of the technical areas adequately, some special task groups were also organized. The four Missouri River Basin Association technical subcommittees and their related task groups are as follows:

- Low Flow/Water Quality Subcommittee
  - Reservoir Water Quality Task Group
- Hydrology/Modeling Subcommittee
- Economics Subcommittee
- Environmental Subcommittee
  - Riverine Fisheries Task Group
  - Reservoir Fisheries Task Group
  - Wetlands Task Group
  - Tern & Plover Task Group

Coordination with the technical subcommittees and special task groups was held at mutually agreeable times, as determined by subcommittee chairs and U.S. Army Corps of Engineers points of contact. They met primarily at the time of the development of study methodology, when refinements were required in methodology, and when verification was needed that the methodology was indeed working appropriately.

In August–October 1992 technical experts participated in an in-depth technical review of the results of implementation of the study methodology. The Missouri River Basin Association Board of Directors, the technical subcommittee and special task group members, and federal representatives reviewed preliminary drafts of the technical reports and analyzed output of the effects models for a set of 69 initial alternatives. This output was documented in an Initial Evaluation Report. The Initial Evaluation Report summarizes the model outputs for the initial alternatives and presents descriptions of some of the key conflicts, compatibilities, and potential tradeoffs between project resources and uses. The state and federal technical review culminated with a workshop involving the Missouri River Basin Association, its technical subcommittees and task groups, and other involved technical experts. Based on input received on the Initial Evaluation Report and the preliminary drafts of the technical reports, changes were made to the economic and environmental impacts models. The revised models were then used to complete the evaluation of a new and larger set of alternatives. A preliminary draft environmental impact statement was prepared that discusses this larger array and its general effects and seven alternatives, which include the existing water control plan, and their detailed effects. The preliminary draft environmental impact statement and drafts of the accompanying technical reports are currently undergoing a second state and federal technical review before completion of a draft environmental impact statement and accompanying final technical reports for review by the public. Even though the development of the impact assessment methodology was expedited and implemented by the U.S. Army Corps of Engineers, it has been significantly affected by the coordination processes implemented by the U.S. Army Corps of Engineers, state and federal agencies, and the Missouri River Basin Association.

Description of the Methodology for Each Resource and Use

Use Categories

Flood Control Economics

Flood damage value functions relate losses to the national economy—National Economic Development, or NED, damages (costs)—for various categories to river flow or reservoir level throughout the study area. The study area is divided into reaches that include each reservoir, each river segment between the reservoirs, and the river segment downstream from Gavins Point Dam. The categories for which monthly value functions were developed are residential, commercial, and industrial buildings; public facilities; crops; and navigation.

Damage was determined by first using computerized hydraulic models to compute the water surface elevation resulting from various flows. If the water surface was high enough to result in flooding, the depth of flooding was determined for the existing development and other uses in the floodplain. Depth of flooding was then combined with information on location, value, and damage susceptibility of existing property to determine damage. Crop damages for a given flood depth were varied on a monthly basis for the distribution of crops normally grown in the floodplain because

the degree of crop damage varies, depending on the season. The loss of navigational traffic was determined by considering the magnitude of river discharge and the length of the interruption during floods.

The LRS Model simulation of river flow computes the average daily flow for each month. These data were not considered appropriate in estimating flood damages. Therefore, the average monthly flow was converted to a monthly peak flow for each month. Historical data on monthly peak flows and average monthly flows were used to determine the adjustments necessary to convert the LRS Model flow data to peak flows. These estimated peak flows are coupled with the value functions to determine damage for the years when historic daily data are available. These damages were used to compare the alternatives' effects on flood control during the alternative evaluation process.

The economic impacts model output initially was in terms of flood damages. To determine maximum damages (potential maximum benefits of the mainstem system of dams), an LRS Model run was made for a run-of-river alternative, which operated for the river reaches as if there were no dams. These theoretical maximum damages were determined for each reach and entered into the economic impacts model as maximum attainable benefits. The economic impacts model then subtracted the damages for each alternative for each reach to determine the flood control benefits for each reach in each month of the 93-year period of record. Using the resulting 1,116 monthly values for the 93-year period of record for each reach analyzed, various flood control benefits, such as the average annual benefits for the full period of record, can be computed for individual reaches or any combination of reaches.

For purposes of determining economic effects on various subparts of the United States, regional economic development economics will be computed (this analysis is only partially complete at this time). The first step is to compute the direct regional effects, which for flood control are considered to be the same as the national economic development benefits. The direct regional economic development flood control benefits, and direct regional economic development benefits for the other uses, were separated by state and the smaller Bureau of Economic Analysis economic areas for input into a model developed by the U.S. Army Corps of Engineers' Institute for Water Resources. This model will be used to help determine the total regional economic development (direct plus indirect) effects on various regional bases. These total regional economic development data will be used to attain an understanding of the effects of the various alternatives on the socioeconomic well being of the various regional areas being analyzed. The size of the regional areas analyzed will be relatively small adjacent to the reservoir and river reaches. The size of the regional areas analyzed will be much larger as the distance from the Missouri River mainstem increases.

Hydropower Economics

Hydropower generated at the mainstem dams comprises 80% of the hydropower capacity in the region in which it is marketed. This represents about 8% of the total power generated in the same region.

National economic development value functions for marketable capacity and energy produced at each dam were developed. These value functions are based on the capacity and energy benefits for each month of the year. Summer and winter benefits are higher because the demands for capacity and energy are greatest in these two seasons. The monthly marketable capacity and energy produced under each alternative are computed by the LRS Model. The LRS Model output is then applied to the value functions to determine monthly values for each month of the 93-year period of record.

The marketable capacity values reflect the changes in the availability of capacity, with higher values for availability during the summer and winter high-power-demand periods. The value of capacity is based on the cost of developing replacement capacity with a 50–50 combination of base-load units (coal-fired steam) and peaking units (oil- or natural gas-fired combustion turbines). The 50–50 combination was selected for the analysis because any loss in capacity from the mainstem system would probably be replaced with a 50–50 mixture of base-load and peaking units. The Integrated Resources Planning Subcommittee of the Missouri Basin Systems Group, which includes many of the power providers and consumers in the region, concurred with the use of this mix. The annual value per kilowatt of generating capacity ($142.17) was distributed among the 12 months of the year based on the changes in demand for power throughout the year to arrive

at a monthly value for each kilowatt of generating capacity provided by the mainstem system hydropower facilities.

The energy-produced values reflect the changes in the production of energy. The unit energy economic values take into account the energy value variability during different times of year, the hydroplant's monthly plant factor, and the operating characteristics of the hydroplant. The values are based on the estimated cost of energy from thermal power plants within the same region that mainstem system hydropower is marketed.

Direct regional economic development hydropower benefits are the same as the national economic development benefits. These benefits are distributed among the various subregions in proportion to the way that mainstem hydropower capacity and energy was marketed in a 5-year period in the mid-1980's.

Lake and River Recreation Economics

Recreation visitation at the Missouri River mainstem reservoirs and river reaches averages about 8.8 million recreation days/year, based on the data used in the study. The recreation benefit evaluation was based on estimation of visitation at differing reservoir water levels and river flows and the computation of unit values for each recreation-day for each reservoir or river reach being analyzed. The product of these two numbers was computed, and the cost of providing a feasible level of recreation services was subtracted from this product, if necessary, for each alternative for each month and each reach in the period of record. The geographical coverage of this analysis included the reservoirs, river reaches downstream from each of the dams, and open river reaches from Yankton, South Dakota, to the mouth at St. Louis, Missouri. Both national economic development and regional economic development unit values were identified in the recreation evaluation.

Extensive data collection efforts were accomplished to develop a model to estimate the visitation value at various reservoir levels or river flows in each reach. These efforts included expenditure surveys of recreation participants, recreational preferences by a sample of licensed anglers, and recreation facility locations and value.

The visitation estimate was based on several sources of data. Visitation was estimated using data from several surveys for the reservoirs and intermediate river reaches and from surveys conducted by the states of Nebraska and Missouri for the river reaches downstream from Gavins Point Dam. Potential changes in visitation were determined based on a model developed by the U.S. Army Corps of Engineers Waterways Experiment Station, using responses to the survey of licensed anglers from each state. These responses were from survey questions regarding number of trips that would be taken at different lake and river levels.

The model output provided estimates of visitation by reservoir level or river flow. Visitation at the reservoirs is also affected by preceding conditions because fishing success is generally higher during the initial period of a declining reservoir. For example, if the reservoir levels are in the decreasing mode, visitation for a given reservoir level will be higher than it would have been if the level had been the same as or higher than the previous year. These differences, referred to as lag effects, are reflected in the value functions that determine visitation.

The national economic development value of a recreation visitor-day was determined through the unit day value methodology. This methodology requires that the visitation to the various reaches be broken down into five categories of recreation: general recreation, general fishing, specialized fishing, generalized hunting, and specialized hunting. Each of these uses has a predetermined unit value based on national willingness-to-pay data, and by taking the percentage of the visitation in each category times these unit values, a total unit value for the distribution of visitation in each reach can be computed. In general, the unit day national economic development benefits are about $7.00 for the three upper, larger lakes and the reach downstream from Fort Peck Dam and in the range of $5.70 to $6.35 for the lower three lakes and other river reaches.

The regional economic development value for recreation is not the same as the national economic development value. Regional values of visitation are based on expenditures for the appropriate mix of residents and nonresidents. This information was obtained from an expenditure survey of recreation participants at the reservoirs and river reaches. The average unit regional economic development values for 1991 and 1992 for the total system are about $32/day for residents and about $35/day for nonresidents.

Recreation visitation is affected by factors such as weather and availability of recreational facilities. Weather should not be a factor in comparing alternatives because it is a constant among alternatives. However, the availability of usable recreational facilities will change among alternatives.

Therefore, the cost of maintaining a feasible level of alternative recreational facilities was computed for each alternative. These costs, which include the costs for boat ramp extensions or replacement, are contained in a capital expenditure cost function, which is related to reservoir level or river flow. As the drought becomes more intense, lower reservoir levels will require the establishment of new access points by extending roads, grading parking lots, and constructing new boat ramps.

Water Quality Economics

The quantity and quality of flows in the Missouri River downstream from Gavins Point Dam are related. The U.S. Environmental Protection Agency has established standards for many chemical parameters. The most critical parameters are oxygen, biochemical oxygen demand, temperature, and ammonia. These parameters are sensitive not only to releases from Gavins Point Dam but also to tributary inflows, time of year, and duration of flow.

Missouri River water quality from Gavins Point Dam to the mouth was modeled using the water quality model QUAL2E developed for U.S. Environmental Protection Agency (Brown and Barnwell 1987). This model was selected because of its wide use, acceptability, and versatility in performing water quality studies. The model was calibrated with data collected in August 1990 on the Missouri River and tributaries (including the Kansas River). The model was verified with data collected in September 1990. Supplemental chlorophyll *a* data were also collected, and an algal component was added to the model. Water quality data from all existing point source discharges along the river are included in the model.

This model was used to simulate water quality conditions under a number of worst-case scenarios. These scenarios were developed by varying Gavins Point Dam releases (9,000–25,000 cfs) and combining these releases with various tributary conditions (i.e., average summer flow, lowest recorded flow), various power plant operating conditions (i.e., maximum capacity, average capacity), and meteorological conditions (i.e., average summer temperature, maximum summer temperature). For each scenario, the model output presented simulated values for temperature, dissolved oxygen, biochemical oxygen demand, organic ammonia and nitrate nitrogen, organic and inorganic phosphorous, and chlorophyll *a* at various points along the river.

Outputs by parameter were compared with Environmental Protection Agency standards to determine if any standards were exceeded under any of the scenarios. In general, no standards were exceeded.

The QUAL2E model is not capable of providing a near field analysis of power plant cooling water discharge. A near field analysis is necessary because state standards dictate that power plant cooling water should not raise the mixing zone temperature by more than 3° C. The mixing zone is generally defined as 25% of the river volume at the point of discharge. There is also a maximum temperature standard that varies among states and river reaches. Therefore, if river temperatures occur that are within 3° C of the maximum, the power plant is restricted to temperature increases of less than 3° C. The river flows necessary to satisfy discharge temperature requirements were computed for each power plant for each month using a temperature mass balance equation. The maximum power plant discharge and change in temperature through the plant at full capacity were obtained from each power plant facility for use in the computations. The computed flow requirement data were coordinated with the various utilities to determine if the computed or an alternative value was being used. In each case, the U.S. Army Corps of Engineers used the value identified as being appropriate by the utilities for the various power plants.

National economic development (the same as regional economic development in the case of water quality and water supply) benefits provided by the operation of the Missouri River mainstem system to the power plants for water quality purposes were included as part of the water supply portion of the model because most of the power plants also have intakes that rely on the Missouri River as a water source. The water quality benefits portion of this water supply computation was based on a three-part computation. First, the costs of buying replacement capacity and energy when flows were inadequate to allow full power plant availability were computed. Second, the capital cost of either a cooling tower or replacement generation, whichever was identified by the utility as being most appropriate, was computed. The lower of these two values was then used as the cost associated with low-flow effects for the power plants. Finally, these costs were subtracted from an optimal benefit value for each power plant to determine the economic benefits for water quality (a portion of the total water supply benefits for the power plants).

For those facilities that had cooling tower construction as an option, it was noted that some reduction in generating capacity occurs with a cooling tower. Depending on the season, a portion of the lost capacity and energy must be replaced by obtaining power on the open market. The cost of this was also included in the computations.

Existing reservoir water quality and sediment data regarding pesticides, metals, and organic compounds were inadequate to relate reservoir operation to the concentration of these constituents in the reservoirs. Additional data were obtained as a first step in a longer-term monitoring program to develop data to better understand potential relationships between reservoir levels at the mainstem projects and water quality. The preliminary draft environmental impact statement discusses reservoir water quality issues from a qualitative standpoint, as the data currently does not exist to discuss it from a quantitative basis.

Water Supply Economics

The national economic development and regional economic development values to water supply intakes for municipal, industrial, power plant cooling, and irrigation water supply were analyzed in the Review and Update. Value functions were developed for each river reach and reservoir that relate water level to capital and variable operating costs. Capital costs include costs for intake modification or construction of a different water source. Variable operating costs include increases in operation and maintenance, pumping, personnel, and emergency costs. Costs may also be incurred because of reductions in power plant output caused by reduced pumping capacity and efficiency. Some of these increases in variable operating costs could continue after intake modification or change to a different source.

Costs for individual intakes were aggregated by river reach or reservoir to develop the value functions. The LRS Model simulations of monthly reservoir level and river flow with rating curves were coupled with the value functions to determine costs for the entire period of record, for each alternative under study. In reaches subject to hydropeaking, the minimum stage associated with a given flow was obtained from the dynamic-flow rating curves and then used to identify costs.

Navigation Economics

The effects of changes to Missouri River mainstem system operation on navigation were evaluated. The Missouri River is part of the larger inland navigation system; therefore, Missouri River and Mississippi River navigation effects were evaluated. Over 90% of the tonnage that moves on the Missouri River also moves on the Mississippi River. The Mississippi River analysis included an evaluation of inland and deep-draft navigation using applicable transportation costing models. Both national economic development benefits and regional economic development impacts were identified. Maximization of national economic development benefits for navigation involves the minimization of operational costs and providing a more efficient mode of transit (transit benefit). Operation and maintenance costs for the navigation channel were subtracted from the transit benefits. Operational costs are related to such factors as barge draft, tow size, and potential delays.

Transit benefits are the difference between the costs of barge transportation and the least-costly alternative mode. This evaluation considers the full origin-to-destination cost of using barge transportation on the Missouri River, including loading, unloading, and transfer costs. Potential least-costly alternatives to barge movement on the Missouri River include an all-land mode using all-rail or all-truck, or combination of the two. Another alternative considered was a multimodal movement using rail or truck to access a Mississippi River port (usually St. Louis) and a barge movement on the Mississippi River for products entering or exiting the Missouri River.

These benefits were computed based on rates and costs provided by a sample of 216 dock-to-dock barge movements during 1987 and 1988 and supplemented by rail and barge costing models. This sample accounted for over 70% of Missouri River tonnage. The current study updated the last rate study that was completed over 12 years ago and included a smaller sample of dock-to-dock movements.

Baseline benefits were developed considering average movements from 1984 through 1988, the most recent 5-year period of near-normal Missouri River navigation. All commercial products were considered, including sand and gravel and noncommercial waterway material transported to maintain the bank stabilization portion of the Missouri River project. In addition, lag-recovery functions following months and years of no navigation were developed based on responses to a survey of terminals and dock operators to capture the lingering impacts of interruptions to navigation.

Annual national economic development navigation benefits for a normal full service, 8-month season total $20.1 million. These benefits were reduced to as low as $7.3 million/year for minimum service (full service minus 6,000 cubic feet per second) and a 6-month split navigation season. No benefits accrue for less than minimum service and a season length of less than 6 months.

Value functions were developed to reflect the relationship between navigational benefits and river flow for each month of the navigation season. Flows below full navigational service levels result in reduced benefits as navigation becomes less efficient. Flows below minimum service levels result in no Missouri River navigation, with the lost traffic diverted to an alternative mode for at least a portion of the movement. National economic development value functions were developed to reflect Missouri River navigation for a range of service levels and a variety of season configurations, including shortened, interrupted, and extended seasons.

The regional economic development value of navigation under each operating alternative is a function of the national economic development navigational benefit and an additional benefit referred to as water-compelled rate savings. Average annual regional economic development effects over the 93-year period of record were computed by the model that included these cost savings for those commodities that are shipped by an alternative mode at rates that are reduced because of the potential of shipping by navigation on the Missouri River. Both regional economic development and national economic development navigation benefits were used to compare alternatives in the evaluation process.

The Mississippi River navigation impacts were based on the costs for daily disruption to full navigation service because of inadequate flows for shallow draft (to New Orleans) and deep draft (New Orleans to the mouth) navigation. Average annual costs were computed from the annual costs for each alternative selected for analysis. The option of operating for a Mississippi River navigation target flow at St. Louis was also evaluated.

Resource Categories

Reservoir Aquatics

Reservoir fish production. Effects on the warmwater and coolwater reservoir fishery (e.g., walleye, white bass, crappie, yellow perch) were considered by predicting annual young-of-the-year (YOY) abundance (production) under the various alternatives. Young-of-the-year are fish that were spawned during the most recent spawning season. Abundance of YOY fish is partially dependent on hydrologic conditions before and during spawning and rearing periods. Through coordination with the Missouri River Basin Association Environmental Subcommittee, it was agreed that YOY abundance is a good indicator of the health of this fishery.

Regression techniques were used to determine what hydrologic variables (i.e., seasonal inflow, seasonal change in water level, area of rearing habitat) affected YOY abundance, based on the past 15–20 years of data provided by the states in which the reservoirs are located. Equations relating YOY abundance to those variables were then developed for two to five warmwater-coolwater species in each reservoir. The species were initially selected based on their importance to the fishery and to represent different spawning or rearing behaviors. The equations were then screened by the Reservoir Fisheries Task Group to drop equations that were not biologically justified.

Simulations of reservoir level and river flow for each alternative were used to compute the value of the hydrologic variables in the equations. A YOY abundance index was then computed for each species and for each year of the period of record. Average annual values for these indices were the basis for comparing the alternatives' effects on this fishery during the alternative screening process.

Reservoir coldwater fish habitat. Effects on the coldwater fishery (trout and salmon) in Fort Peck Lake, Lake Sakakawea, and Lake Oahe, and on the potential for establishing one in Lake Francis Case, were considered by determining the amount of coldwater habitat available under each alternative. This was accomplished by the use of predictive equations that relate coldwater habitat to reservoir level and discharge. Coldwater habitat is defined as water colder than 15° C that contains greater than 5 ppm dissolved oxygen. The amount of coldwater habitat is considered the primary factor that affects this fishery and that can be affected by system operation.

An existing U.S. Army Corps of Engineers water quality model, CE-QUAL-W2 (U.S. Army Corps of Engineers 1986), was used to simulate the volume of coldwater habitat available in the reservoirs. The model was run with a number of operating alternatives using a 30-year synthetic period of record. The alternatives and 30-year

period were selected so that a wide range of reservoir levels and discharges result. Running the water quality model resulted in simulations of coldwater habitat for many different combinations of reservoir levels, discharges, and summer climatic conditions. These factors influence the amount of coldwater habitat. Regression techniques were applied to these data to develop equations relating coldwater habitat volume to monthly reservoir levels and discharge.

Simulations of monthly reservoir levels and discharge were coupled with the equations to obtain the amount of coldwater habitat for each month of the period of record. These 1,116 volumes were further reduced to the minimum volume available in each year for each alternative to compare the alternatives' effects on the coldwater fishery during the alternative evaluation process.

In addition to the above analysis, the state of Montana was interested in knowing how much habitat is available under the various alternatives for lake trout that use the face of Fort Peck Dam as spawning habitat. A relationship between reservoir level and potential habitat area was developed for this analysis.

Riverine Aquatics

Riverine fish physical habitat. Evaluation of effects on the native riverine warmwater fish community was based on historic, predevelopment habitat conditions. The evaluation assumes that these habitat conditions represent the ideal situation for all species native to the Missouri River ecosystem, including the endangered pallid sturgeon. This approach is not species specific, but rather it recognizes that the entire community was dependent on these unique physical habitat conditions.

Water-surface elevations and historic cross sections in various channel types below four of the reservoirs (except Oahe and Big Bend) were used to describe depth and velocity distributions for each month based on the preregulation monthly flow. These distributions for each river reach were assumed to define the ideal physical habitat conditions for that month.

Present-day cross sections and water-surface elevations were used to develop depth and velocity distributions that would occur today for a range of monthly flows. These distributions were compared with the historic distributions and assigned a correlation coefficient ranging from 0 to 1 that describes how well they match the historic distributions. Therefore, the value functions relate flow to a value (correlation coefficient) that represents how well that flow matches the unique physical habitat diversity of the historic river.

Another approach was used for five reaches comprising the Missouri River from Sioux City to the mouth near St. Louis. Riverine biologists from the four states adjacent to the lower river identified optimal flows for the native riverine species based on their considerable experience in working with the various riverine species, and on water surface elevations and velocities at various cross sections in this river reach. Values ranging from 0 to 1 were assigned to the various flows comprising the full range of potential flows on this river reach.

These value functions were applied to the LRS Model monthly flow simulations to obtain a value for each month of the period of record. Annual values were computed for each reach by summing the values for each of the 12 months of the year. Total physical habitat values were computed by summing the values for all nine reaches. In the alternative evaluation process, average annual values were compared to evaluate the effects of the alternatives on the physical habitat of the native riverine fish community.

Riverine Fish Temperature Habitat. The previous discussion described the evaluation of effects on the physical habitat of the native riverine fish community. Effects on water temperature were also evaluated because it is also an important habitat component. Most of the species that make up the native warmwater community spawn during spring and early summer months. Therefore, temperature criteria for the months of April, May, June, July, and August were developed to describe temperatures necessary to initiate spawning and provide appropriate incubation and rearing habitat.

Simulations of monthly flow and release temperatures from the reservoir water quality model were input to a riverine water quality model CE-QUAL-RIV1 (U.S. Army Corps of Engineers 1990). This model was used to predict the length of river in each reach that meets the temperature criteria from April through August for each year of the period of record. This simulation was accomplished for each alternative, and the average annual values of the average monthly values for the 5-month periods were used in the alternative evaluation process.

Coldwater sport fisheries exist below Fort Peck, Garrison, and Oahe dams. The same riverine

water quality model used for the warmwater fisheries was used to predict the length of river that meets coldwater temperature criteria for the months from April through September below Fort Peck and Garrison dams.

Emergent Wetlands and Riparian Habitat

Evaluation of the alternatives' effects on emergent wetlands and riparian habitat along the Missouri River began with a survey of 41 representative sites from the headwaters of Fort Peck Lake downstream to near St. Louis, Missouri. These included typical sites in each of the three large reservoirs—Fort Peck Lake, Lake Sakakawea, and Lake Oahe—and in the river reaches between reservoirs. Several of these sites include abandoned oxbows of the Missouri River, and several were in the reservoir delta areas.

Emergent wetland and riparian habitat were surveyed and mapped at the sites following the Cowardin classification system (Cowardin et al. 1979). Mapping included acreage and elevations of each habitat type occurring on the site. About 11 wetland and 3 riparian types were used in the classification, which included flood plain forests, riverine wetlands, and wetlands adjacent to the reservoirs.

An extensive literature search was conducted to develop rules for each habitat type. The rules describe the hydrologic conditions under which a particular habitat type would change to another type. These rules were based on how the plant species within a habitat type respond to various flooding and drought conditions. Factors considered include the species' tolerance to the length and frequency of flood and drought seasons. The species' structural and life-cycle characteristics, such as dispersal, colonization, growth form, and plant age, were also considered.

Using the existing habitat conditions from the survey as a starting point, LRS Model simulations of monthly reservoir levels and river stage were applied to these rules to determine the number of acres of each category of habitat types for each year of the period of record. This was accomplished for each alternative.

The average annual acreage of each habitat type for each of the 93 years was used as the basis for comparing the alternatives' effects on wetlands and riparian habitat. The Environmental Subcommittee was consulted to determine which categories should be added together to comprise the wetland and riparian habitat acres. To arrive at a single average annual value for wetland habitat, the corresponding values for the various reaches were summed. Similarly, the acres of total riparian habitat were also computed. The average annual data on the acres of wetland habitat and riparian habitat were then compared to determine the effects of the various operating alternatives on these resources.

Wildlife

Evaluation of the alternatives' effects on wildlife was based on the emergent wetland and riparian habitat analysis. Important species of wildlife associated with particular wetland and riparian habitat were identified in conjunction with the Missouri River Basin Association Environmental Subcommittee. Effects on these species (e.g., white pelican, commorant, Canada goose, furbearers) were based on the acreage of this habitat that would be available throughout the period of record.

Tern and Plover Habitat

The tern and plover impacts analysis used value functions that relate the amount of available sand bar nesting habitat to river stage (elevation) in each reach below each dam except Oahe and Big Bend dams. Aerial videography was flown at three different river stages, and the extent of sand bar habitat was determined at each stage using a map image processing system called MIPS (Sidle and Ziewitz 1990). These data were used to produce the sand bar acreage-versus-stage relationship that currently exists in each river reach.

Rules that describe the hydrologic conditions that cause vegetation to become established on or removed from sand bars were developed from the literature. Too much vegetation establishment makes sandbars unsuitable for nesting by terns and plovers. These rules were applied to the LRS Model simulations of monthly flow for each month of the period of record and for the current sand bar profile conditions to determine the amount of sandbar habitat with varying levels of vegetation for each year. A new sand bar acreage-versus-stage relationship was then developed for each year. This process basically models vegetation establishment on or removal from sand bars for each alternative over the period of record.

The resulting sand bar vegetation data for each year were then coupled with the corresponding year's LRS Model flow simulations and the corre-

sponding maximum stage from the dynamic-flow model. The amount of sand bar habitat suitable for tern and plover habitation available for 2 consecutive months during the nesting season for each year was determined. The average of these annual values for suitable habitat were computed and form the basis for comparing the alternatives' effects in the alternative evaluation process.

Historic Properties

All historic properties located within the authorized maximum pool areas are ultimately subject to damage or destruction from reservoir operations. The alternatives may influence rates of effects or, in some cases, the exact kinds of effects. However, long-term effects will probably be similar, regardless of the alternative.

The evaluation of the alternatives' effects on this nonrenewable resource is a matter of discriminating between the immediate seriousness of effects from the different proposals. Most of the many known sites have not been fully evaluated as to significance or character. An alternative might greatly reduce immediate high-bank erosion loss at one project and greatly increase the same problem at one of the other projects, owing to geomorphology, storage balance at the three large reservoirs, prehistoric cultural location preferences, fetch characteristics, and soil variability.

The evaluation compared an approximate degree of systemwide immediate erosion threat from each alternative. Physical destruction of archaeological content through erosion is by far the single most damaging effect of reservoir operations. Other known effects of reservoir water management, including inundation, wetting and drying, relic hunting, biophysical alterations, and variations in chemistry, are not as significant.

Initial evaluation of the potential effects on historic properties were based on identification of known sites within sequential elevation bands around Lake Sakakawea and Lake Oahe. This evaluation assumed that a damaging effect would occur from 5 feet above to 3 feet below any given reservoir pool elevation. Each month that the water surface was within this range for a given site was included as being undesirable. A value function was developed that identified the number of sites within elevation bands on these two reservoirs. Using the LRS Model data, the number of sites potentially affected in each month was recorded by the environmental impacts model, and an average annual value was computed based on the annual sums of the 12 monthly values in each year. The higher the average annual value, the more adverse the effect on historic properties. An equation was developed to convert this value to one that resulted in a higher value or benefit for a reduced number of sites adversely affected.

The analysis of Fort Peck was undertaken similarly, but with less data available. Site distribution at Fort Peck Lake was modeled primarily on a sample survey conducted in 1991. Fort Peck Lake shoreline erosion characteristics are very different from those of Lake Sakakawea and Lake Oahe. Cultural distribution is also different, as are site characteristics and geomorphology.

Results

The average annual values obtained by interfacing the value functions with LRS Model monthly simulations of reservoir levels and river flows over the period of record were used to compare the alternatives' effects on the mainstem system's resources and uses during the alternative evaluation process. To demonstrate the results of this methodology, average annual impact data for seven alternatives are presented. The first four alternatives follow the overall philosophy of the current Water Control Plan, which has the following pertinent water control parameters: permanent reservoir system pool in millions of acre-feet (MAF); a minimum winter nonnavigation target flow in thousands of cubic feet per second (kcfs); a spring/fall nonnavigation target flow in kcfs; and a summer nonnavigation target flow in kcfs. Specifically, the corresponding values for these parameters for the first four alternatives are as follows:

Alternative	Permanent Pool (MAF)	Winter Target (kcfs)	Spring/Fall Target (kcfs)	Summer Target (kcfs)
1	18	12	9	9
2	18	12	9	25
3	31	12	9	25
4	44	12	9	25

The other three alternatives break from the general philosophy of the current Water Control Plan somewhat to provide a more natural riverine flow to benefit environmental resources. These alternatives provide more flow in the spring and early summer and include 2 summer months of no navigation support (August and September). The

Table 1. Average annual environmental resource values for the 93-year simulation period.

Alternative	Wetland (1,000 acres)	Riparian (1,000 acres)	Tern and plover (acres)	Young-of-year fish prod. (index)	Reservoir coldwater (MAF)	River coldwater (miles)	River warmwater (miles)	River physical habitat (index)	Historic properties (index)
1	150.69	105.06	310.0	1.129	10.10	190.7	48.9	53.13	4,605
2	162.55	101.28	438.4	1.273	10.98	191.7	49.9	53.84	4,320
3	163.03	99.37	437.8	1.296	11.22	192.5	48.3	53.71	4,272
4	160.79	98.47	457.8	1.334	11.82	195.9	45.0	53.28	4,031
5	163.25	89.83	415.7	1.248	11.19	184.0	51.9	59.28	4,445
6	165.47	89.10	406.2	1.313	11.58	186.7	49.6	59.24	4,382
7	158.34	87.66	424.6	1.370	12.56	194.2	45.2	59.51	4,000

Table 2. Average annual NED benefits for the 93-year simulation period ($ millions).

Alternative	Flood control	Hydropower	Water supply	Recreation	Navigation	Total NED
1	41.10	625.52	546.00	48.13	16.19	1,276.94
2	40.84	628.71	547.30	48.74	16.39	1,281.98
3	40.68	632.16	546.90	49.38	12.55	1,281.67
4	40.58	636.73	547.60	50.28	9.29	1,284.48
5	39.04	624.55	535.30	47.85	9.86	1,256.60
6	38.42	629.04	535.20	49.15	8.60	1,260.41
7	37.86	634.11	532.40	49.42	6.13	1,259.92

only variation among these three alternatives is the permanent pool level as follows:

Alternative	Permanent Pool (MAF)
5	18
6	31
7	44

The results for each of the seven alternatives averaged over the 93-year period for each environmental resource and economic use category are summarized in Tables 1 and 2, respectively.

Conclusions

The values identified during the alternative evaluation process helped identify key resource-use conflicts and compatibilities and major trade-offs among the alternatives. A large array of alternatives could be evaluated effectively using the impact assessment methodology selected. Also, the methodology provided adequate detail for definition of specific effects associated with a smaller set of alternatives. The preliminary draft environmental impact statement has been prepared and distributed for a technical review by various federal and state agencies and Indian tribes before preparing the draft environmental impact statement for public review. The Preliminary Draft Environmental Impact Statement contains two chapters on the evaluation of alternatives. The first of these chapters, Chapter 4, discusses the trends associated with changes in the resource and use values for the full array of alternatives evaluated for the Draft Environmental Impact Statement. Chapter 5 presents the results of the detailed analysis of seven alternatives. Conclusions reached to date on the evaluation of alternatives are contained in Chapter 6 of the preliminary draft environmental impact statement; however, this version of the environmental impact statement does not identify a preferred alternative. A determination will be made at the time that the draft environmental impact statement is being completed whether to present a preferred alternative for public comment. This alternative may or may not be one of the seven alternatives evaluated in detail at this time. A preferred alternative will be identified in the final environmental impact statement.

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The Powder River: A Relatively Pristine Stream on the Great Plains

by

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Abstract. The Powder River is an 800-km-long tributary of the Yellowstone River that originates in central Wyoming and flows through a basin that is sparsely populated and semi-arid. The Powder River is a turbid, saline, meandering stream with a highly braided, unstable sand bottom. Discharge is highly erratic, and the river is intermittent during dry years upstream from the mouth of Clear Creek, 16 km upstream from the Montana–Wyoming state line. The river is unique in that the fish community of 32 species is composed primarily of endemic fishes (25 species). A limited sport fishery for channel catfish (*Ictalurus punctatus*) occurs in the river during spring and early summer. Several large riverine species, including the shovelnose sturgeon (*Scaphirhynchus platorynchus*) and channel catfish, are known to migrate long distances over the length of the river in spring associated with spawning. The sturgeon chub (*Macrhybopsis gelida*), a species of special concern, is common in the river. Agricultural irrigation is the dominant water use in Montana and Wyoming. The primary threat to the fish community is water development, which could lead to dewatering, blockage of migration, or loss of sediment flows and turbidity with changes in water quality and channel configuration. Fisheries management focuses on preservation of natural habitat and the fish community in the river system.

The Powder River is a tributary to the Yellowstone River in a remote area of northeastern Wyoming and southeastern Montana. The Powder River has been relatively unaffected by water development, channelization, introduction of exotic species, exploitation of fish stocks, and other human effects common among rivers in the United States. It is a low-gradient stream with poorly developed riparian areas, highly fluctuating flows, extremely high turbidity, and a very unstable sand bottom (Rehwinkle et al. 1978; Gerhardt 1989). The river channel is shallow and highly braided, and it meanders substantially within the flood plain. European settlers characterized the Powder River as "a mile wide and an inch deep, too thin to plow and too thick to drink."

The Powder River is 800 km long including its longest fork, the South Fork (Rehwinkle et al. 1978). The Powder River is formed near Kaycee, Wyoming, at the confluence of the South Fork and Middle Fork of the Powder River, 160 km upstream from the Montana–Wyoming state line (Figure). The South Fork originates in high plains, while the Middle Fork originates in the Bighorn Mountains. At the confluence, the South Fork has the features of the lower Powder River, with a braided, sand-bottom channel, while the Middle Fork has a more confined channel with gravel riffles and stable, vegetated banks. Most of the flow is contributed by the Middle Fork (Annear 1992).

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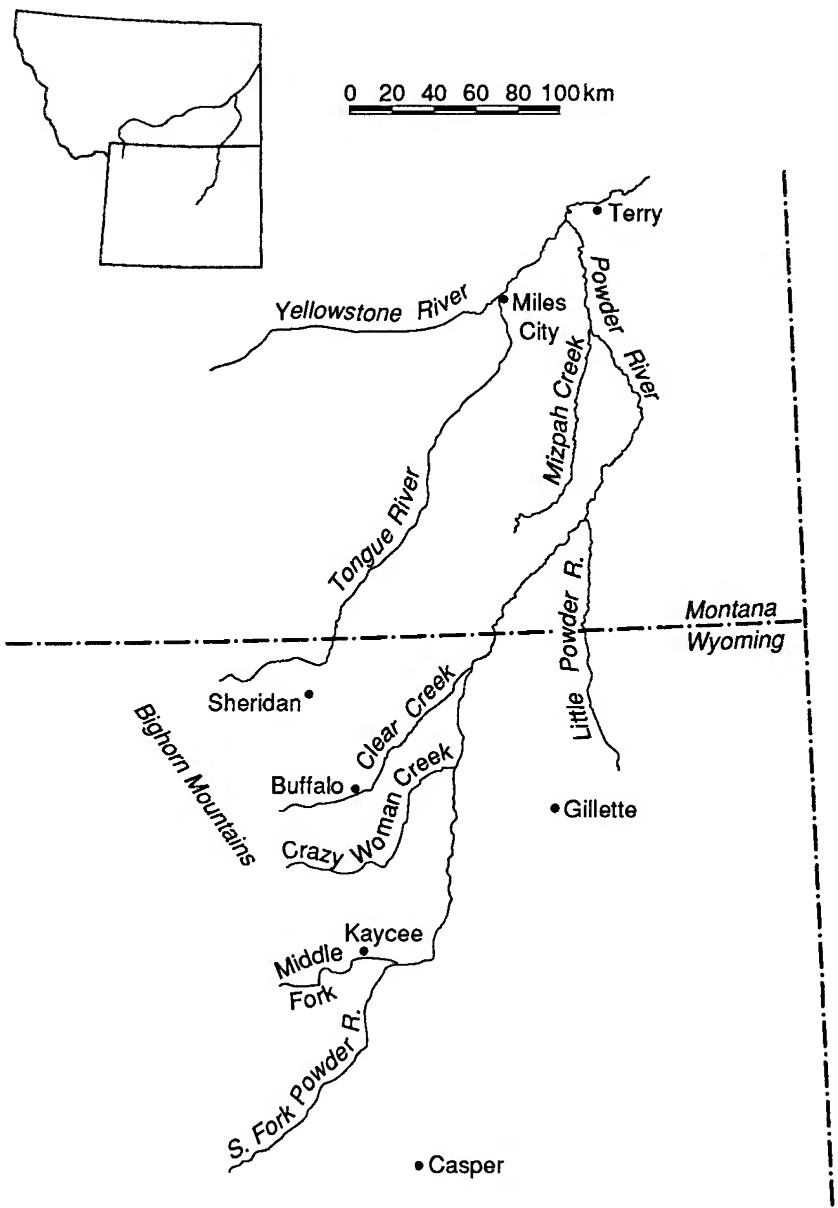

Figure. Map of the Powder River system in Montana and Wyoming.

Along the course of the Powder River, there are only four tributaries that provide flows into the Powder River during most years—Crazy Woman Creek and Clear Creek in Wyoming, and the Little Powder River and Mizpah Creek in Montana. The tributaries tend to have more well-developed riparian areas, less turbid water, and more stable bottom substrates than the Powder River.

The Powder River flows through a semi-arid basin with upland vegetation dominated by grasses and sagebrush (*Artemisia*). The primary land uses are livestock grazing and energy extraction (coal, oil, natural gas).

Drainage Basin

The Powder River basin is 34,300 km^2 (Rehwinkle et al. 1978; Elser et al. 1980). Elevation ranges from 770 m above mean sea level at the confluence of the Powder River with the Yellowstone River near Terry, Montana, to 3,950 m at the headwaters

of the North Fork Powder River in the Bighorn Mountains. Most of the drainage is high plains, with dominant physical features including high plateaus dissected by deep stream-cut canyons, badlands, and river terraces (Rehwinkle et al. 1978). A thick series of sedimentary rocks dating back to the Cambrian period have accumulated in the basin (Hodson et al. 1971; Rehwinkle et al. 1978). The sedimentary material is limestone, sandstone, shale, siltstone, and gypsum, and it is moderately to highly erodible. Air temperatures up to 38° C in summer and down to −34° C in winter are common within the basin (Rehwinkle et al. 1978).

Crazy Woman Creek is the most upstream tributary, flowing into the Powder River 64 km upstream from the Montana–Wyoming state line (Annear 1992). It originates in the Bighorn Mountains as a fast-flowing mountain stream, but it takes on the characteristics of a slow, meandering plains stream with turbid, warm water as it flows onto the plains (Smith 1988). The creek drains 2,450 km^2 and has no barriers to upstream movement by fish from the Powder River. Fish habitat in the form of gravel–cobble riffles, deep pools, overhanging banks, and large woody debris is common in Crazy Woman Creek (Smith 1988). Average peak discharge at the mouth of Crazy Woman Creek was 4.3 m^3/s, with a maximum of 82.2 m^3/s, between 1940 and 1982 (Annear 1992). The creek is known to become intermittent during dry summers (Smith 1988; Gerhardt 1989), with several periods of no measurable flow between 1940 and 1982 (Annear 1992).

Clear Creek joins the Powder River 16 km upstream from the Montana–Wyoming state line and is the largest tributary in Wyoming (Annear 1992); the drainage area is 3,930 km^2 (Eiserman 1962). Channel and habitat features are similar to those of Crazy Woman Creek. Within the foothills of the Bighorn Mountains, Clear Creek flows are influenced by Lake DeSmet and Healey Reservoir, and the stream is truly perennial (McDowell 1986). Average peak flow at the mouth was 18.7 m^3/s between 1940 and 1982, and average minimum flow was 1.8 m^3/s (Annear 1992). In 1988, there was no measurable surface flow in the Powder River upstream from the mouth of Clear Creek in late summer and fall (Gerhardt 1989). A low, concrete diversion dam 1 km upstream from the mouth of Clear Creek seems to serve as a barrier to upstream fish passage during low-flow periods (Smith 1988; Gerhardt 1989; Annear 1992). A large water diversion dam 11 km upstream totally prevents upstream migration by fish (Gerhardt 1989).

The Little Powder River is the largest tributary in Montana. It flows into the Powder River 249 km upstream from the confluence with the Yellowstone River. Rehwinkle et al. (1978) described the Little Powder River as having gravel bottom areas with riffles, similar to the tributaries in Wyoming.

Mizpah Creek is a more downstream tributary to the Powder River and is similar to the other tributaries. Among the sites studied by Rehwinkle et al. (1978) in the Powder River system, Mizpah Creek had the greatest diversity of fish, indicating that it has substantial habitat diversity.

Four additional tributaries—Sheep Creek, Locate Creek, Coal Creek, and Tenmile Creek—flow into the Powder River downstream from Mizpah Creek, but they are frequently intermittent.

Hydrology

Annual precipitation in the Powder River basin ranges from 0.74 m in the Bighorn Mountains (mainly as snow) to 0.31 m in the extreme northern plains portion of the drainage. The average for the plains is less than 0.37 m/year (Rehwinkle et al. 1978). Water yield from nonmountainous drainages is generally less than 0.0036 $m^3/s/km^2$, while from the mountains it is more than 0.022 $m^3/s/km^2$ (Hodson et al. 1971). The hydrograph for the Powder River is commonly bimodal; it has a small peak in March followed by a large peak in June associated with snowmelt and runoff from the mountains (Hodson et al. 1971). Following runoff, flows decline steadily to lows during summer, fall, and winter; there is some variation during summer associated with storm events (Gerhardt 1989). During dry years, the Powder River upstream from Clear Creek becomes intermittent. Stream flows are highly variable from year to year depending largely on snowpack in the Bighorn Mountains (Annear 1992). Discharge near the mouth has averaged 17.6 m^3/s, with an extreme of 878 m^3/s in 1943 (Elser et al. 1980).

Water Quality

The Powder River is naturally turbid and saline because it flows through highly erodible sedimentary material (Hodson et al. 1971; Montana Department of Natural Resources and Conservation

1979). Turbidity in the Powder River can be as high as 5,800 Jackson Turbidity Units (JTU), with total dissolved solids as high as 3,500 mg/L (Rehwinkle et al. 1978; Montana Department of Natural Resources and Conservation 1979). Turbidity commonly exceeds 500 JTU, and total dissolved solids frequently exceed 1,300 mg/L. Turbidity is highest is spring and summer following thunderstorms (Annear 1992). Total dissolved solids peak following storms and in late summer when irrigation return flows make up much of the stream flow (Annear 1992). Turbidity and total dissolved solids tend to be less in tributaries than in the Powder River.

Total dissolved solids in excess of 1,000 mg/L are considered high from an agricultural perspective and unsuitable for irrigation of most crops unless careful management is employed (Montana Department of Natural Resources and Conservation 1979). Similarly, water with total dissolved solids greater than 500 mg/L is not considered acceptable for drinking (U.S. Public Health Service 1962). Consequently, demand for water from the Powder River for either irrigation or municipal use has not been high.

Water temperature in the Powder River is highly variable. Rockett (1974) measured summer water temperatures in the river at the Montana–Wyoming state line. Water temperature exceeded 27° C for 39 days in midsummer. Daily variations of 13° C were observed in August.

Floodplain Vegetation

Narrow riparian areas with cottonwoods (*Populus* spp.) and willows (*Salix* spp.) occur along the Powder River, the four tributaries, and ephemeral watercourses. Gerhardt (1989) described the riparian areas along the Powder River as poorly developed but those along the tributaries as more substantial. Rehwinkle et al. (1978) described riparian vegetation as occurring in patches along the Powder River in Montana and estimated that 6,010 ha of riparian vegetation were present along the banks. They estimated an additional 1,066 ha on islands over a 140-km reach between Powderville, Montana, and the Montana–Wyoming state line.

Portions of the floodplain of the Powder River and its tributaries are irrigated primarily to produce hay. Rehwinkle et al. (1978) stated that there were 15,150 ha of irrigated land in the Montana portion of the Powder River basin in 1976. The extent of irrigation along the Powder River is greater in Montana than in Wyoming and has not increased substantially since the mid 1970's.

Biotic Productivity

The biotic productivity of the Powder River is low relative to other rivers, owing to high turbidity, poor water quality, variation in flow, unstable bottom substrate, and high seasonal temperatures (Rehwinkle et al. 1978; Montana Department of Natural Resources and Conservation 1979). Poor light penetration is believed to lead to low production of aquatic invertebrates (Rehwinkle et al. 1978). Densities of aquatic macroinvertebrates sampled with an Eckman dredge ranged from 55 to 486 organisms/m^2, but Rehwinkle et al. (1978) indicated that the macroinvertebrate community is unique among streams in Montana. The biotic productivity of the tributaries is believed to be higher than in the Powder River because of lower turbidity, better water quality, and more stable substrates (Rehwinkle et al. 1978).

Fish Assemblages

The Powder River and its four tributaries support a diverse assemblage of fish; 32 species are known to occur (Table), 25 of which are native. Most of these species are tolerant of widely fluctuating environmental conditions, especially turbidity, salinity, discharge, and water temperature (Smith 1988; Smith and Hubert 1989). The common species in the river are flathead chub, *Hybognathus* spp. (brassy minnow, plains minnow, western silvery minnow), sturgeon chub, goldeye, river carpsucker, shorthead redhorse, stonecat, common carp, longnose dace, and channel catfish (Rehwinkle et al. 1978; Smith 1988).

A variety of salmonids—cutthroat trout (*Oncorhynchus clarki*), rainbow trout (*O. mykiss*), golden trout (*O. aquabonita*), brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), lake trout (*S. namaycush*), and Arctic grayling (*Thymallus arcticus*)—have been introduced to the coldwater streams and lakes in the Bighorn Mountains and foothills area (Eiserman 1962; Baxter and Simon 1970; B. Stewart, Wyoming Game and Fish Department, Sheridan, personal communication). These species are not residents of the Powder River because of the environmental conditions that are present. However, salmonids are captured

Table. Warmwater fish that have been collected from the Powder River and its tributaries in Montana and Wyoming.[a]

Common name	Scientific name	Native
Shovelnose sturgeon	*Scaphirhynchus platorynchus*	x
Paddlefish	*Polyodon spathula*	x
Goldeye	*Hiodon alosoides*	x
Northern pike	*Esox lucius*	
Common carp	*Cyprinus carpio*	
Creek chub	*Semotilus atromaculatus*	x
Flathead chub	*Platygobio gracilis*	x
Sturgeon chub	*Macrhybopsis gelida*	x
Lake chub	*Couesius plumbeus*	x
Longnose dace	*Rhinichthys cataractae*	x
Sand shiner	*Notropis stramineus*	x
Brassy minnow	*Hybognathus hankinsoni*	x
Plains minnow	*Hybognathus placitus*	x
Western silvery minnow	*Hybognathus argyritis*	x
Fathead minnow	*Pimephales promelas*	x
River carpsucker	*Carpiodes carpio*	x
Shorthead redhorse	*Moxostoma macrolepidotum*	x
Smallmouth buffalo	*Ictiobus bubalus*	x
White sucker	*Catostomus commersoni*	x
Longnose sucker	*Catostomus catostomus*	x
Mountain sucker	*Catostomus platyrhynchus*	x
Black bullhead	*Ameiurus melas*	x
Yellow bullhead	*Ameiurus natalis*	
Channel catfish	*Ictalurus punctatus*	x
Stonecat	*Noturus flavus*	x
Burbot	*Lota lota*	x
Brook stickleback	*Culaea inconstans*	x
Smallmouth bass	*Micropterus dolomieu*	
Rock bass	*Ambloplites rupestris*	
Green sunfish	*Lepomis cyanellus*	
Sauger	*Stizostedion canadense*	x
Walleye	*Stizostedion vitreum*	

[a] Information from Eiserman (1962), Baxter and Simon (1970), Rehwinkle et al. (1978), Elser et al. (1980), Smith and Hubert (1989), and Watson and Stewart (1991).

occasionally in the river and warmwater portions of the tributaries (Smith and Hubert 1989).

A wider diversity of fish is found in the tributaries than in the river. For example, Rehwinkle et al. (1978) reported 15 species from Mizpah Creek, and Smith (1988) found at least 15 species in Crazy Woman Creek.

The game species found in the Powder River and its tributaries include black bullhead, channel catfish, stonecat, burbot, smallmouth bass, rock bass, green sunfish, shovelnose sturgeon, sauger, and walleye. However, the channel catfish is the only species that occurs in sufficient abundance to support a sport fishery (Rehwinkle et al. 1978; Gerhardt and Hubert 1991).

The channel catfish stock in the Powder River and its tributaries includes a substantial proportion of large fish, up to 21 years old (Smith and Hubert 1988; Gerhardt 1989; Gerhardt and Hubert 1991). The channel catfish grow at a rate that is average for riverine stocks across North America despite the low biotic productivity in the Powder River (Smith and Hubert 1988; Gerhardt and Hubert 1991). Low annual mortality and limited exploitation explain the high proportion of large fish in the stock (Smith and Hubert 1988; Gerhardt and Hubert 1991). Interviews with anglers indicate that channel catfish provide a sport fishery in the Powder River and its tributaries, but only in late spring and early summer (Rehwinkle et al. 1978).

Many of the large riverine fish in the Powder River seem to be highly migratory, including shovelnose sturgeon, goldeye, common carp, river

carpsucker, channel catfish, burbot, and sauger (Mueller 1968; Elser et al. 1977; Rehwinkle et al. 1978; Rockett 1979; Smith 1988; Gerhardt 1989; Annear 1992). Upstream movement by channel catfish before spawning in mid June, with spawning in both the Powder River and Clear Creek, has been observed (Gerhardt 1989; Gerhardt and Hubert 1990). Returns of tags indicate that channel catfish and shovelnose sturgeon captured in Wyoming during early summer move downstream to the lower portions of the Powder River in Montana or to the Yellowstone River later in the summer (Gerhardt 1989; Annear 1992).

Large shovelnose sturgeon (mean standard length = 75 cm) are commonly captured in the Powder River during spring and early summer (Smith 1988; Annear 1992). However, the fish do not seem to be in the Powder River, Wyoming, every year. Annear (1992) determined that sustained high flows in the Powder River of 26 m^2/s in June are needed for shovelnose sturgeon to move upstream to the vicinity of Crazy Woman Creek. Such flows occurred in 3 years between 1983 and 1991, and shovelnose sturgeon were captured in only those 3 years. A rock ledge extends across the Powder River 8 km downstream from the Montana–Wyoming state line. The ledge may serve as a natural barrier to upstream movement except at above average flows.

Data on relative abundance indicate that shovelnose sturgeon, goldeye, channel catfish, and sauger are present in tributaries during early summer but absent by late summer, when flows have declined (Rehwinkle et al. 1978; Smith 1988; Gerhardt 1989; Smith and Hubert 1989; Annear 1992). Trends in relative abundance also indicate that common carp and river carpsucker are more abundant in tributaries in early summer than later in summer (Smith 1988; Smith and Hubert 1989).

The large riverine fish may migrate upstream during runoff in spring to spawn in tributaries or upstream areas of the Powder River. The tributaries provide more stable substrates and gravel–cobble riffles; more abundant cover in the form of boulders, large woody debris, and overhanging banks; and lower turbidity and salinity than are found in the Powder River. The tributaries seem to be destination points for spawning fish, and they may provide nursery habitat for some species (Rehwinkle et al. 1978; Smith 1988; Smith and Hubert 1989).

Smith and Hubert (1989) suggested that the fish community found in Crazy Woman Creek, Clear Creek, and the Powder River in Wyoming may be divided into four assemblages: creek–river migrants, creek residents, river residents, and creek–river residents. Creek–river migrants—goldeye, common carp, river carpsucker, channel catfish, and sauger—move from downstream in the Powder River into tributaries to spawn and then move back downstream into the river. Creek residents live in the creeks throughout their lives; these species include fathead minnow, longnose sucker, white sucker, and black bullhead. River residents are species that live in the Powder River throughout their lives, but the large species may migrate upstream to spawn. River residents include the sturgeon chub and the more migratory shovelnose sturgeon and burbot. Creek–river residents are species that occur in the Powder River and its tributaries throughout the year. These include flathead chub, longnose dace, sand shiner, *Hybognathus* spp., shorthead redhorse, and stonecat. The only fish species found in the Powder River that may be considered unusual is the sturgeon chub. It is relatively common in the Powder River (Rehwinkle et al. 1978; Stewart 1981) but is considered rare in other waters of Wyoming and Montana (Baxter and Simon 1970; Rehwinkle et al. 1978). The sturgeon chub has been identified as a species of special concern by the American Fisheries Society (Williams et al. 1989). A species of special concern is one that may become threatened or endangered by relatively minor disturbances to its habitat.

Fish Assessment

Routine sampling of the fish in the Powder River has not been conducted by any of the fisheries management agencies. The Montana Department of Fish, Wildlife, and Parks recently initiated sampling in the lowest 13.5 km of the river in an effort to locate pallid sturgeon (*Scaphirhynchus albus*) within the Yellowstone River system (Watson and Stewart 1991). The Wyoming Game and Fish Department has sampled or has sponsored sampling in the Powder River and Crazy Woman Creek since 1983 to determine the occurrence of shovelnose sturgeon (Smith 1988; Annear 1992).

Sampling of fish in the Powder River is difficult because of the extreme turbidity and salinity, and the shifting sand bottom in most areas of the river (Rehwinkle et al. 1978; Smith 1988). The most

effective sampling gear seems to be hoop nets (Smith 1988; Gerhardt 1989; Gerhardt and Hubert 1989; Annear 1992), but they tend to become inundated with sediment in many portions of the river, especially during high water. Gerhardt and Hubert (1989) found that cheese bait did not affect the catch rate of channel catfish in hoop nets in June, but doubled the rate in July and August.

Fish Harvest

The only sport fish that is harvested from the Powder River in appreciable numbers is the channel catfish (Rehwinkle et al. 1978). Gerhardt and Hubert (1991) estimated the annual exploitation rate to be only 2%. They also estimated that substantial changes in the length frequency distribution of channel catfish in the river would occur if exploitation was increased.

There are no commercial fisheries in the Powder River. Gerhardt and Hubert (1988) determined that the migratory patterns of channel catfish, extreme fluctuations in flow, and limited productivity of the Powder River would not allow a commercial fishery for channel catfish.

Fisheries Management

The fish community in the Powder River has remained essentially unaltered by the introduction of exotic fish. Species that have been introduced to the Powder River basin include several salmonids in the headwaters, but they are extremely rare in the warm portions of the tributaries and the Powder River (Smith 1988). Introduced species include common carp, smallmouth bass, rock bass, green sunfish, and walleye. The common carp is the only species that has become relatively common in the Powder River (Rehwinkle et al. 1978; Smith 1988). Smallmouth bass and rock bass are found in Clear Creek but are rarely captured in other portions of the river system. Green sunfish and walleye occur in the Powder River and its tributaries but they are seldom captured (Smith 1988).

No special regulations have been applied to the Powder River in either Montana or Wyoming. General statewide harvest regulations apply in both states.

There is no supplemental stocking of fry or fingerlings to enhance sport fisheries in either Montana or Wyoming. Purposeful introductions of channel catfish, smallmouth bass, rainbow trout, and brown trout have been made in midportions of Clear Creek by the Wyoming Game and Fish Department (R. McDowell, Wyoming Game and Fish Department, Sheridan, personal communication).

Habitat Management

The Powder River represents a unique river system, owing to the extreme environmental conditions that occur. Consequently, it has a fish community that is also unique. Therefore, habitat management in the Powder River system focuses on preservation of existing habitat for maintenance of endemic species.

One aspect of habitat management is to protect the tributaries to the Powder River. Tributaries provide spawning and nursery habitat for riverine fishes (Rehwinkle et al. 1978; Smith 1988; Gerhardt 1989; Smith and Hubert 1989), and they support unique fish assemblages (Smith 1988; Smith and Hubert 1989). Seasonal movement of riverine fishes into tributaries may be essential to the continued maintenance of several species, such as shovelnose sturgeon, goldeye, river carpsucker, shorthead redhorse, channel catfish, and sauger (Rehwinkle et al. 1978; Smith 1988; Annear 1992).

A second aspect of habitat management is preservation of existing flows, turbidity, and water quality in the Powder River. The endemic fishes in the Powder River have evolved life history strategies that allow them to survive in extreme conditions. Water development that alters discharge patterns, reduces turbidity, changes water quality, modifies sediment transport, or blocks migratory routes for fish is likely to result in changes in the fish community.

The Tongue River is another tributary to the Yellowstone River that flows through Wyoming and Montana. The Tongue River probably had a fish community similar to the Powder River before water development (Smith 1988; Smith and Hubert 1989). In contrast to the Powder River, the fish community of the Tongue River has been influenced by the construction of Tongue River Dam for storage of irrigation water, by four downstream diversion dams, and by several introduced species (Elser et al. 1977). Seven species, including goldeye, shovelnose sturgeon, and sturgeon chub, are now found only below the farthest downstream diversion dam. Downstream from Tongue River Dam the flows have become less varied, substantial vegetation has developed in the riparian zone

to stabilize the banks, and the water is less turbid. Following water development, some river residents (shovelnose sturgeon) and creek-river migrants (goldeye) were eliminated from the Tongue River, and some creek residents (white suckers and black bullheads) became more abundant in the river. Also, species introduced into the reservoir as sport fish became established in the Tongue River (northern pike, black crappie, *Pomoxis nigromaculatus*). Water development in the form of reservoirs and diversion dams on the Powder River would probably alter the native fish community as in the Tongue River. Access to Clear Creek by river fish has been blocked 11 km upstream from the mouth by a large diversion dam (Gerhardt 1989). Upstream from the dam several fish found downstream are not present, including goldeye and channel catfish. Barriers to fish movement would probably have similar effects on other tributaries to the Powder River.

Smith (1988) made several recommendations regarding habitat management in the Powder River system: (1) prevent dewatering of tributaries in the summer caused by irrigation; (2) prevent dams from being constructed that provide barriers to fish movement, serve as sediment traps, and alter water quality; and (3) prevent alteration of natural stream channels through channelization and other anthropogenic modifications.

Effects of Cultural Intervention

Several municipalities and agricultural interests have constructed small impoundments on small tributaries to the Powder River in the mountains and foothills. Communities currently using water from the Powder River drainage include Sheridan, Buffalo, Dayton, Ranchester, and Kaycee, Wyoming (Hodson et al. 1971). These water developments have probably reduced flows in the lower tributaries and in the Powder River.

Owing to the salinity of the water in the Powder River (Montana Department of Natural Resources and Conservation 1979), its utility for irrigation and domestic use is limited. However, use of water from the Powder River for industrial purposes, such as coal gasification, has also been considered (Rehwinkle et al. 1978). Under the terms of the Yellowstone River Compact, the states of Montana and Wyoming each receive an allocation of water from the Powder River, 58% of the unappropriated water to Montana and 42% to Wyoming (Montana Department of Natural Resources and Conservation 1979). According to the compact, Montana may acquire land and easements to construct and operate water projects in Wyoming to develop its allocation. Several reservoirs have been proposed for the Powder River and its tributaries (Mueller 1968, 1972; Rockett 1973; Montana Department of Natural Resources and Conservation 1979; Annear 1983), but neither state is actively pursuing development at this time.

The largest use of surface water in the Powder River basin is for irrigation along stream valleys (Hodson et al. 1971). At present, water from Crazy Woman Creek and Clear Creek is used primarily for irrigation. The extent to which irrigation influences flows in Crazy Woman Creek and Clear Creek is unknown.

Value of the Resource

The Powder River and its tributaries have limited economic value because of the poor water quality in the river. Higher water quality in the headwater streams makes their water more desirable for agricultural and municipal uses. Some water development has occurred within the Powder River basin, but Clear Creek seems to be the tributary that has been most altered.

The fish community of the Powder River is unique. It probably represents the kind of community that was found in free-flowing Great Plains rivers. Similar rivers have been modified by water development and do not have either the habitat or the fish community currently found in the Powder River. A special value of the Powder River is that it is a remnant of a Great Plains river ecosystem. At least one species found in the Powder River, the sturgeon chub, may be listed as threatened or endangered, and consequently, the river could be designated as critical habitat for this species.

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The Yellowstone River: Its Fish and Fisheries

by

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Abstract. The Yellowstone River is one of the Nation's few remaining free-flowing rivers. Although a variety of perturbations, including introduced species, water withdrawals, agricultural and energy developments, and logging have affected and continue to threaten the Yellowstone, it retains much of the character it had at the time of the Lewis and Clark expedition in 1806. The Yellowstone originates in northwestern Wyoming and flows generally northeasterly through a drainage basin of 182,336 km^2 to its confluence with the Missouri River in North Dakota, 1,091 km downstream. Average gradient ranges from 2.44 m/km in the upper reaches to 0.53 m/km in the lower reaches. Historic mean annual discharge ranges from 87 to 358 m^3/s at Corwin Springs (river km [rkm] 885) and Sidney (rkm 47), Montana. Turbidity is seasonally high and increases downstream of the Powder River confluence. Water quality is generally good. Fish communities include 56 species representing 16 families. The Yellowstone River supports a trout fishery in the upper reaches and a warmwater fishery in the lower reaches. Number of fish species increases from 16 in the upper river to 30 in the transition zone, to 49 near the mouth. The river supports an abundance of aquatic invertebrates, with species richness and biomass decreasing downstream. Although the Yellowstone has no dams, three major irrigation diversions influence fish movement. Agricultural development in the basin has affected the river and its biota, primarily by water diversion. Increasingly restrictive angling regulations have been necessary to maintain some gamefish populations. Fishing pressure is highest in the salmonid zone and generally decreases downstream. Exploitation rates are generally low because of low effort or special regulations. The lower river provides spawning habitat and supports an important fishery for paddlefish. The lower river also has a small population of endangered pallid sturgeon. No pallid sturgeon reproduction has been documented for more than a decade. At present, instream flow reservations for fish are maintaining the relatively unaltered character of the Yellowstone. A new pilot program to lease water for instream needs will include up to three tributaries to the upper Yellowstone that are unavailable for cutthroat trout spawning and rearing.

As the longest free-flowing river in the contiguous United States, the Yellowstone River is a unique and priceless resource. It is a rare model of the structure and function of large western rivers. Although indigenous cultures have inhabited the Yellowstone valley for about 12,000 years, Captain William Clark was the first to report the wonders of the Yellowstone River to western civilization. On the return trip of their famous 1806 expedition, Captains Lewis and Clark split the expedition into two parties. While Meriwether Lewis and his party descended the Missouri, Captain Clark explored the Yellowstone from a point near present-day Livingston, Montana, to its confluence with the

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Missouri. He described the abundance and diversity of wildlife and extensive cottonwood forests in the river bottom. Although a variety of perturbations, including introduced species, water withdrawals, agricultural and energy developments, and logging have affected and continue to threaten the Yellowstone, it retains much of the character it had in Clark's day.

Location

The mainstem of the Yellowstone originates in northwestern Wyoming near the southeastern border of Yellowstone National Park (Fig. 1). It flows generally northeasterly through a drainage basin of 182,336 km^2 to its confluence with the Missouri River in extreme western North Dakota, 1,091 km downstream. Seven of the Yellowstone's nine major tributaries—the Gardiner, Boulder, Stillwater, Clarks Fork, Bighorn, Tongue, and Powder rivers— enter from the south; the Lamar River enters from the east, and the Shields River flows from the north.

Climate

The Yellowstone River basin includes portions of four ecoregions: the middle Rocky Mountains, Wyoming Basin, Montana Valley and Foothill Prairies, and the Northwestern Great Plains (Omernick and Gallant 1987). Elevations in the basin range from 3,660 m in the alpine headwaters of the Absaroka, Beartooth, Wind River, and Bighorn mountains to less than 610 m at the mouth. Precipitation ranges from more than 210 cm in the mountains to less than 38 cm on the plains. Most of the precipitation in the mountains is in the form of late winter and early spring snow, whereas on the plains most of the annual precipitation is received as early summer rainfall (Koch et al. 1977). Mean annual air temperatures range from 0 to 8° C; the greatest range of temperatures occurs on the plains.

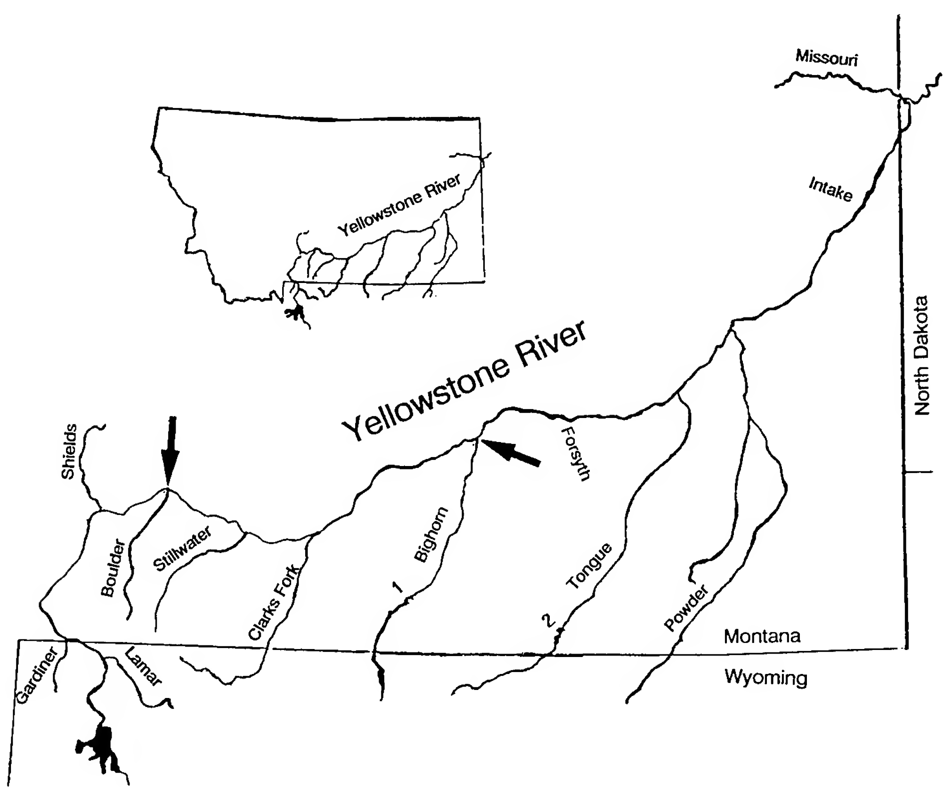

Fig. 1. The Yellowstone River, its major tributaries, and Bighorn (1) and Tongue River (2) reservoirs. *Arrows* mark the beginning and end of the transition zone.

Vegetation

The composition of riparian plant communities along the Yellowstone River varies with the climate and the proximity and elevation of the site to the river channel and the associated disturbance caused by flooding. Pioneer plant communities on newly deposited alluvial bars are typically willow (*Salix* spp.), followed by cottonwood (*Populus* spp.). Mid-sere vegetation consists of forests of mature cottonwoods, which persist for about 100 years. Cottonwoods form extensive forests on the islands and banks of the lower Yellowstone River. In sites left undisturbed by flooding, cottonwoods eventually disappear, and climax vegetation becomes established (Boggs 1984).

Climax vegetation in the riparian zone varies along the length of the river. On the cooler and wetter upper river, climax is often Douglas fir (*Pseudotsuga menziesii*), while in the middle reaches of central Montana, Rocky Mountain juniper (*Juniperus scopulorum*) is climax. In the lower reaches of east-central Montana, where rainfall declines to only 25–36 cm annually, climax vegetation is a grassland community consisting of blue grama (*Bouteloua gracilis*) or western wheatgrass (*Agropyron smithii*). Farther downstream, in extreme eastern Montana and western North Dakota, annual rainfall increases to 36–51 cm, and forests of green ash (*Fraxinus pennsylvanica*) and bur oak (*Quercus macrocarpa*) form the climax community (Boggs 1984; Silverman and Tomlinsen 1984).

Geologic Setting

The Yellowstone River originates in the Absaroka Mountains southeast of Yellowstone National Park at an elevation of about 3,048 m. In the park it forms Yellowstone Lake, a caldera created 600,000 years ago by the most recent major eruption of the volcanoes in this geologically active area (Fritz 1985). Below Yellowstone Lake, the river flows through deep canyons of erodible volcanic ash and forms large waterfalls where it encounters more resistant lava flows (Silverman and Tomlinsen 1984). The park is surrounded by mountain ranges associated with the Laramide orogeny of the Late Cretaceous, which occurred about 70 million years ago.

As the river leaves the mountains, it flows over mainly Quarternary alluvial deposits; farther downstream on the plains the basin is largely composed of Tertiary sediments. Two major structural features exist in the lower basin, the Porcupine Dome, located north of Forsyth, Montana, and the Cedar Creek anticline, which runs northwest from Baker to Glendive, Montana (Koch et al. 1977). Pleistocene glaciers advanced southward far enough during the Wisconsin glaciation to block the river and form glacial Lake Glendive near present-day Glendive, Montana (Alden 1932).

Fluvial Geomorphology and Hydrology

Virtually all of the characteristics of the Yellowstone that retain any of their pristine character (hydrology, geomorphology, water quality, and biotic communities) do so primarily because the river remains undammed. However, although the Yellowstone proper is undammed, 31% of the drainage basin (mostly in the Bighorn River basin) is upstream of storage reservoirs (Koch et al. 1977).

The general morphological character of the Yellowstone River remains the same as it was when Captain Clark explored the river in 1806. Reaches that were braided with wooded islands, as well as reaches with fewer islands and bars, still exhibit these general characteristics. Channel pattern varies from sinuous to braided to irregular meanders. Sinuosity values (ratio of channel length to down-valley distance) in the middle and lower river range from 1.14 to 1.36. Slope generally declines with distance downstream, ranging from 0.89% in the upper river to 0.14% near Billings to 0.046% near the North Dakota border (Koch et al. 1977; Fig. 2).

The channel is often braided or split, particularly in the lower river. The formation of long side channels or sloughs, called irregular lateral activity, is also common on the lower Yellowstone. Islands and bars range from large, stable islands with mature vegetation to unvegetated point and midchannel bars composed of sand or gravel. Conditions identified by Leopold et al. (1964) as necessary for establishment of braided channels are transport of bed material, erodible channel banks, and rapid stage fluctuation. Bed material is largely gravel in the upper reaches, grading to sand about 20 km above the mouth (Koch et al. 1977).

Because the mainstem is yet undammed, the Yellowstone retains a largely natural hydrograph (Fig. 3). The high spring flows resulting from snowmelt in the mountainous regions are one of the most important parts of the channel-forming process.

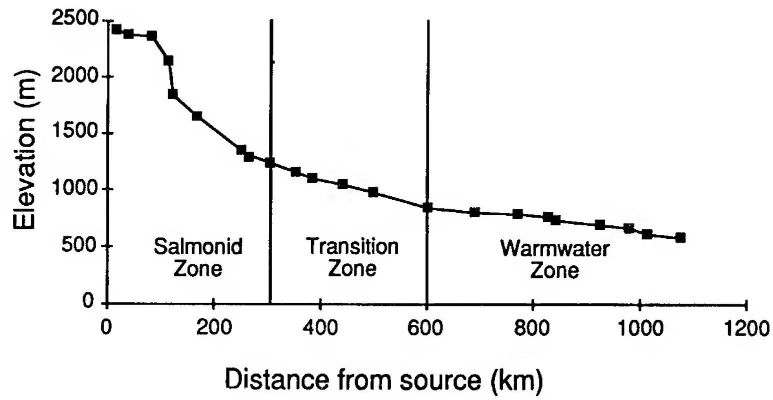

Fig. 2. Longitudinal profile and fish community zones of the Yellowstone River.

These high flows initiate bed load transport and cause the erosion and deposition necessary for the formation of bars, which may later become islands. Although localized flooding occurs in winter because of ice dam formation and breakages, spring flooding is most important in determining channel form. Humans have had minimal effect on channel morphology, largely through riprapping, closing side channels, and clearing bank vegetation, which promotes erosion. The effects of agriculture and timber harvest have not been documented.

The mean annual discharge of the river near the mouth is 362 m^3/s. The largest flood in 78 years of record was 4,500 m^3/s. The lowest flow on record was only 13.3 m^3/s. Average annual discharge is 9.3 million acre-feet (U.S. Geological Survey 1990).

The Bighorn River is the Yellowstone's largest tributary, with a mean annual discharge of 110 m^3/s. The confluence is at river km (rkm) 476. Damming of the Bighorn River in 1966 caused an 80% reduction in annual sediment yield (over 5 million metric tons) from that basin. The Yellowstone has not yet shown any reduction in sediment transport at a gauging station near the mouth of the river (Koch et al. 1977), which indicates that the Yellowstone may be out of equilibrium below the Bighorn and is degrading its bed and banks to produce the extra sediment.

Water Quality

Although water quality in the Yellowstone shows a general deterioration from source to mouth, it is generally good and free from major pollution inputs. Dissolved oxygen levels are usually near saturation, biological oxygen demand levels indicate no organic pollution, and fecal coliform levels are low. Dissolved metals only occasionally exceed water use criteria. Total suspended solids, total dissolved solids, turbidity, sulfate, and temperature increase in the lower river (Karlich and Thomas 1977).

Macroinvertebrate Communities

The macroinvertebrate communities of the Yellowstone River are not well known. The most complete survey is that of Newell (1977). He studied the

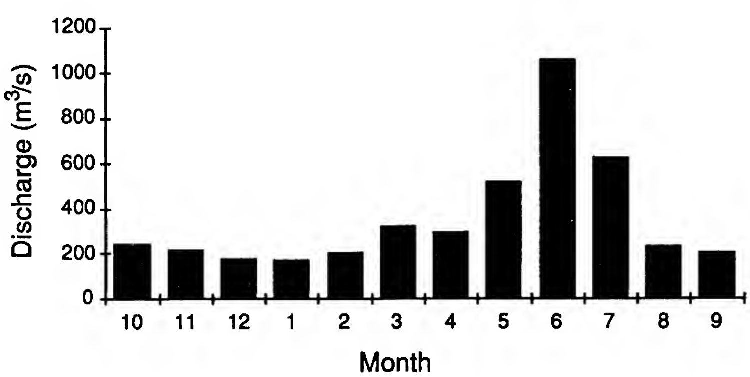

Fig. 3. Mean monthly flows of the Yellowstone River at Sidney, Montana (river km 47), for water years 1924–32, 1934–92.

macroinvertebrate communities at 20 sites from just below Yellowstone National Park to just above the confluence with the Missouri River. Benthic sampling was conducted during late summer and fall 1975 using kick nets, Water's round samplers, and Hester-Dendy artificial substrates. Limited sampling of adult ephemeropterans (mayflies), plecopterans (stoneflies), and trichopterans (caddis flies) was also conducted.

Newell (1977) found a rich macroinvertebrate fauna on the Yellowstone that was dominated by mayflies, caddis flies, and true flies; 154 taxa of benthic macroinvertebrates were collected, although recent collections have added to Newell's list (D. Gustafson, Montana State University, Bozeman, personal communication). Density was highest in November samples and ranged from 12,000 individuals/m^2 to less than 100 individuals/m^2. Species richness and density declined downstream.

Thirty-seven species of mayflies were found, and the community exhibited a gradual change from a mountain fauna in the upper reaches to a prairie fauna more adapted to the slower current velocities, warmer temperatures, and finer substrates of the lower river. Mayfly species richness was reasonably constant along the entire river and ranged from 19 species at a site in the salmonid zone to 10 species at the two lowermost stations (Fig. 4). Four species (*Acentrella insignificans, Diphetor hageni, Heptagenia elangantula,* and *Rhithrogena undulata*) were collected at every station, and a fifth (*Ephemerella inermis*) was collected at all stations but the lower two.

Stoneflies were diverse but not abundant in the upper river; 37 species were identified in the study area. Species richness was highest in the upper river; 21 species were captured at the uppermost station, and species number declined rapidly downstream, particularly in the transition zone (Fig. 4).

The distribution of caddis flies was similar to that of stoneflies, with a steady decline in species richness with distance downstream (Fig. 4). No caddis flies were collected at the lowermost station. The genera *Hydropsyche* and *Cheumatopsyche* were found throughout the river and dominated the macroinvertebrate fauna in the lower 10 stations. Thirty-six species were identified; however, Newell (1977) believed that more will be found as more intensive sampling is performed and as adult males are collected to facilitate identification to the species level.

Dipterans, particularly chironomids, were found throughout the river and were the most abundant and diverse of the remaining macroinvertebrate groups. Coleopterans were found in all zones; odonates and hemipterans were found only in the transition and nonsalmonid zones; and lepidopterans were rare. Noninsect macroinvertebrates were in the classes Turbellaria, Oligochaeta, and Mollusca, the crustacean orders Isopoda and Amphipoda, and the arachnid order Acari. Of the noninsect groups, only the Oligochaeta were abundant.

Herpetofauna, Birds, and Mammals

Riparian areas, which are ecotones between aquatic and upland areas, are vital habitats for many reptiles, amphibians, birds, and mammals. Particularly in arid and semi-arid environments, the importance of these habitats can hardly be overstated. For example, of five reptiles on Montana's Species of Special Concern list (Genter 1991), three use riverine or riparian habitat along the

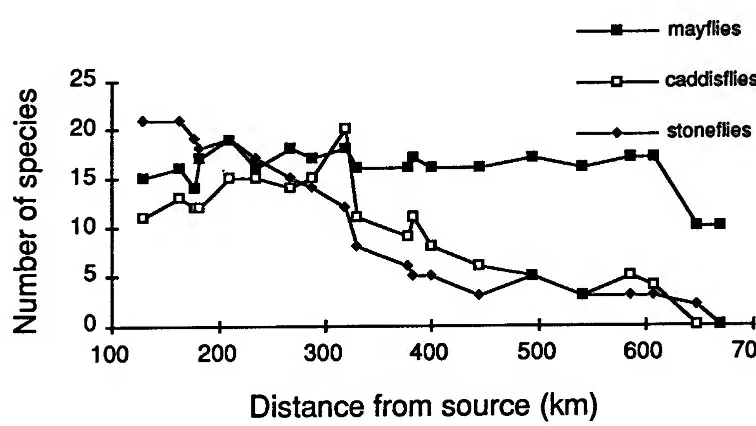

Fig. 4. Species diversity of mayflies, caddis flies, and stoneflies at 20 sampling stations along the Yellowstone River. Adopted from Newell (1977).

Yellowstone River. The highest known density of nesting birds on the North American continent occurs in southwestern riparian cottonwood forests (Johnson et al. 1977). A study of the wildlife on the lower Yellowstone near Glendive, Montana, showed that the riparian forest had the highest avian density and diversity of 10 habitat types elevated (Silverman and Tomlinsen 1984).

The areas adjacent to the Yellowstone River have been famous for their diversity and abundance of wildlife since the days of Captain William Clark, who reported the vast herds of elk, bison, and pronghorn antelope. The distribution of mammals along the Yellowstone is much different today (Thompson 1982). Many large species have suffered severe declines, shrinking ranges, or have been completely extirpated. Grizzly bear and bison, once common, now only occupy the vicinity of Yellowstone National Park. Gray wolves have been extirpated, and mountain lions are now rare along the lower river. Elk are found only in the vicinity of the upper river, and rarely in the riparian zone (Silverman and Tomlinsen 1984).

Composition of the Fish Community

The Yellowstone River supports a diverse fish community composed of 56 species representing 16 families (Table 1; Peterman 1979; Holton 1990; Montana Interagency Stream Fishery Data Base 1992). Among these is one federally listed endangered species and three state listed fishes of special concern. Fishes of special concern are defined as native fishes that have limited numbers or specialized habitat requirements and could become threatened or endangered (Holton 1980, 1986). Twenty species found in the Yellowstone River (36%) are not native to the drainage. Except for a few sport fishes, little is known about the populations and ecology of most species.

From its headwaters in Wyoming to its mouth in North Dakota, the Yellowstone changes from a coldwater alpine system to a warmwater prairie river. Fish community complexity increases from a simple coldwater community in the headwaters to a diverse warmwater community downstream, as is typical of this type of system (Fremling et al. 1989; Rahel and Hubert 1991). Based on fish distribution, the Yellowstone River can be divided into three zones: an upper coldwater or salmonid zone, a transition zone inhabited by both coldwater and warmwater species, and a lower warmwater zone (Haddix and Estes 1976; Peterman 1979). Although temperature records are neither complete nor continuous, maximum summer water temperatures within these zones, as reported by U.S. Geological Survey (1991) for the period of record, were 23° C at Livingston, Montana (rkm 801), 26.5° C at Billings (rkm 584), and 29° C at Sidney (rkm 47). In 1990 and 1991 the maximum temperature between the Upper Falls and Yellowstone Lake was 20° C. Longitudinal changes in the fish community seem to be related to downstream increases in temperature. Biotic zonation in streams has often been related to thermal conditions (Huet 1959; Balon and Stewart 1983; Moyle and Herbold 1987; Rahel and Hubert 1991).

The salmonid zone of the Yellowstone River, as defined by Peterman (1979), extends 357 km from the Yellowstone headwaters (rkm 1,091) to the mouth of the Boulder River (rkm 734) and is inhabited by 16 fish species representing six families (Table 1). Vaughn (Montana Department of Fish, Wildlife and Parks, Billings, personal communication) believes the salmonid zone would be better defined as extending downstream to the mouth of the Clarks Fork River. The fish community in the upper reach, between Upper Falls and Yellowstone Lake, contains only two native species: Yellowstone cutthroat trout and longnose dace. Two introduced species, redside shiner and longnose sucker, occur in small numbers, but the community is dominated by cutthroat trout. Redside shiners have not been reported below the falls. Of the 14 fish species known to occur in the remainder of the salmonid zone (Table 1), only 7 are abundant in a portion or all of this reach (mountain whitefish, rainbow trout, brown trout, cutthroat trout, longnose sucker, white sucker, and mottled sculpin; Montana Interagency Stream Fishery Data Base 1992).

The transition zone between the primary coldwater environment of the upper river and the warmwater environment of the lower Yellowstone extends about 258 km from the Boulder River to the mouth of the Bighorn River (rkm 476; Peterman 1979). Beginning at Huntly Diversion (rkm 566), abundance of warm water species rapidly increases downstream (M. Vaughn, Montana Department of Fish, Wildlife and Parks, Billings, personal communication). The transition zone contains 30 fish species representing 7 families. Salmonid populations all but disappear, while goldeye

Table 1. Fish species reported from the Yellowstone River with distribution by zone. Each zone is divided into thirds. (A = abundant, C = common, R = rare). Distribution from Brown (1971), Holton (1990), and Montana Interagency Stream Fishery Data Base (1992). Common and scientific names follow Robins (1991).

Species	Zone 1[a]	Zone 2[b]	Zone 3[c]
Acipenseridae			
Shovelnose sturgeon *Scaphirhynchus platorynchus*	AA		
Pallid sturgeon *Scaphirhynchus albus*	RR		
Polyodontidae			
Paddlefish *Polyodon spathula*	CA		
Hiodontidae			
Goldeye *Hiodon alosoides*	R	RAA	AAA
Cyprinidae			
Common carp[d] *Cyprinus carpio*	RR	RRR	AAA
Goldfish[d] *Carassius auratus*		RR	RRR
Golden shiner *Notemigonus crysoleucas*			RRR
Creek chub *Semotilus atromaculatus*			RRR
Pearl dace *Margariscus margarita*			RRR
Longnose dace *Rhinichthys cataractae*	RRR	RRR	CCC
Northern redbelly dace *Phoxinus eos*			RRR
Lake chub *Couesius plumbeus*	R	RRR	RRR
Flathead chub *Platygobio gracilis*		CC	AAA
Sturgeon chub *Macrhybopsis gelida*			RRC
Emerald shiner *Notropis atherinoides*		C	AAA
Sand shiner *Notropis stramineus*			RRR
Redside shiner *Richardsonius balteatus*	R		
Brassy minnow *Hybognathus hankinsoni*			RRR
Plains minnow *Hybognathus placitus*			RRR
Western silvery minnow *Hybognathus argyritis*		R	CCC
Fathead minnow *Pimephales promelas*		RR	CCC
Catostomidae			
River carpsucker *Carpiodes carpio*		CC	AAA
Blue sucker *Cycleptus elongatus*			CC
Smallmouth buffalo *Ictiobus bubalus*		U	CCC
Bigmouth buffalo *Ictiobus cyprinellus*			CCC
Shorthead redhorse *Moxostoma macrolepidotum*	RR	CCC	AAA
Longnose sucker *Catostomus catostomus*	RAA	AAC	CCC
White sucker *Catostomus commersoni*	AA	AAA	AAA
Mountain sucker *Catostomus platyrhynchus*	RC	CRR	RRR
Ictaluridae			
Black bullhead[d] *Ameiurus melas*		R	RRR
Yellow bullhead[d] *Ameiurus natalis*			RRR
Channel catfish *Ictalurus punctatus*		CC	AAA
Stonecat *Noturus flavus*		RC	AAA
Esocidae			
Northern pike[d] *Esox lucius*			RRC
Osmeridae			
Rainbow smelt[d] *Osmerus mordax*			R
Salmonidae			
Mountain whitefish *Prosopium williamsoni*	AAA	ACR	
Cutthroat trout *Oncorhynchus clarki*	AAC	CR	
Rainbow trout[d] *Oncorhynchus mykiss*	CAA	ACR	RRR
Brown trout[d] *Salmo trutta*	AAA	ACR	RRR
Brook trout[d] *Salvelinus fontinalis*	RRR	R	
Gadidae			
Burbot *Lota lota*	R	RCC	AAA
Cyprinodontidae			
Plains killifish *Fundulus zebrinus*			RR
Cottidae			
Mottled sculpin *Cottus bairdi*	AAA		
Percichthyidae			
White bass[d] *Morone chrysops*			R
Centrarchidae			
Rock bass[d] *Ambloplites rupestris*			RR
Green sunfish[d] *Lepomis cyanellus*			RRR

Table 1. *Continued.*

Species	Zone 1[a]	Zone 2[b]	Zone 3[c]
Pumpkinseed[d] *Lepomis gibbosus*			RRR
Bluegill[d] *Lepomis macrochirus*		R	
Smallmouth bass[d] *Micropterus dolomieu*		C	ARR
Largemouth bass[d] *Micropterus salmoides*		R	RRR
White crappie[d] *Pomoxis annularis*			RRR
Black crappie[d] *Pomoxis nigromaculatus*			RRR
Percidae			
Yellow perch[d] *Perca flavescens*		R	RRR
Sauger *Stizostedion canadense*		CC	AAA
Walleye[d] *Stizostedion vitreum*		R	RCC
Sciaenidae			
Freshwater drum *Aplodinotus grunniens*		R	CCC

[a] Salmonid zone, river km (rkm) 802–993.
[b] Transition zone, rkm 477–801.
[c] Warmwater zone, rkm 0–476.
[d] Introduced species.

and burbot increase in abundance (Table 1). New species include sauger, walleye, five cyprinids, river carpsucker, and three species of catfish.

The largest change in the fish community occurs in the 476-km warmwater section of the lower Yellowstone. Two acipenserids, one esocid, seven cyprinids, two catostomids, one ictalurid, one cyprinodontid, one osmerid, six centrarchids, and one sciaenid are added, bringing the total number of species in this zone to 49 (Montana Interagency Stream Fishery Data Base 1992). Fifteen of the 16 families of fishes inhabiting the Yellowstone River are represented here.

The most ubiquitous species in the Yellowstone River is white sucker, classed as abundant in all three river zones (Table 1). Goldeye, common carp, longnose dace, shorthead redhorse, burbot, longnose sucker, mountain sucker, rainbow trout, and brown trout also occur in all river zones. Rainbow trout and brown trout do not reproduce in the warmwater zone, and shorthead redhorse, carp, and goldeye do not reproduce in the coldwater zone (Peterman 1979).

Status of Game Fishes

Fifteen species of game fishes occur in the Yellowstone River, seven (47%) of which are introduced. Native species are Yellowstone cutthroat trout, mountain whitefish, channel catfish, burbot, sauger, pallid sturgeon, shovelnose sturgeon, and paddlefish. Introduced sport species are rainbow trout, brown trout, brook trout, northern pike, smallmouth bass, largemouth bass, and walleye.

The four trout species and mountain whitefish are the only game fishes of the upper Yellowstone River. The stream reach from the boundary of Yellowstone National Park to the mouth of the Boulder River represents the longest single reach (166 km) of blue ribbon trout stream in Montana, making up 23% of the state's 727 km of blue ribbon waters (Peterman 1979). This section supports an excellent fishery for rainbow trout, brown trout, and, in the upper reaches, cutthroat trout; brook trout are rare. Mountain whitefish are several times more abundant than trout and provide an important winter fishery (Berg 1975; Peterman 1979).

The Yellowstone cutthroat trout is the only trout native to the Yellowstone River drainage. Its natural range and abundance have been greatly diminished, and it has been designated as a species of special concern. The extent of historical downstream distribution is unknown, but Evermann and Cox (1896) reported that cutthroat trout were abundant in the Tongue River drainage. Today, fluvial populations of Yellowstone cutthroat trout in the Yellowstone River drainage are restricted to the mainstem and tributaries upstream of the Boulder River (rkm 734; Clancy 1988).

Environmental degradation, introduction of nonnative fishes, and human exploitation have led to the reduction in range and abundance of Yellowstone cutthroat trout. In Montana they occur in only 8% of their former range (Hadley 1984). For at least the last 30 years, Montana fishery biologists have been aware of the continuing loss of Yellowstone cutthroat trout populations (Hadley 1984). Similar loss of other subspecies has occurred or is occurring throughout the western United States (Behnke 1972, 1988, 1992).

The first effects on Yellowstone cutthroat trout abundance probably resulted from exploitation. Evermann and Cox (1896) stated that small parties caught as many as 800 cutthroat trout with hook and line in a few days in the Tongue River. They reported that there "is so much fishing done now in the region that most residents are of the

opinion that if something is not done to stock the stream its fame as a fishing resort will soon be lost." Whether exploitation of this subspecies was historically a major factor in its decline is unclear (Hadley 1984). However, given its high vulnerability to angling (Griffith 1972; Hadley 1984; Gresswell 1985; Varley and Gresswell 1988) and unrestricted harvest in the early 1900's, exploitation probably had an important effect.

Introduction of rainbow trout and brown trout was a major factor in the decline in pure populations of Yellowstone cutthroat trout. These species are now abundant throughout the salmonid zone of the river. Fluvial populations of cutthroat trout are often displaced by non-native trouts through interspecific competition (Hanzel 1959; Hadley 1984; Fausch 1988). Since Yellowstone cutthroat trout evolved in the absence of other trout species, there was no opportunity for natural selection to produce differences in resource use to ameliorate competition (Fausch 1988; Griffith 1988). Although the year of introduction into the Yellowstone River is unknown, rainbow trout and brown trout were first introduced in Montana in 1889 (Brown 1971). Rainbow trout were extensively stocked in the Yellowstone River until 1972 (Clancy 1988).

In addition to displacement from its former range by competition, there continues to be a significant decline in genetically pure populations of Yellowstone cutthroat trout. Many of the remaining populations have been genetically contaminated through hybridization with rainbow trout (Hadley 1984) and other stocks of cutthroat trout. Leary et al. (1989) found introgression with rainbow trout in 30–40% of Yellowstone cutthroat trout populations in the upper drainage.

Currently, the Yellowstone cutthroat trout population in Yellowstone National Park is probably at historic levels of abundance, although no density information is available. In areas downstream of the park where cutthroat trout occur in sufficient abundance to make estimates, biomass was lowest (2.8 kg/0.3 km) near Livingston, where rainbow trout and brown trout biomass was greatest, and highest (11.8 kg/0.3 km) just below the park boundary (Montana Interagency Stream Fishery Data Base 1992). Population estimates in these areas in 1991 were 26/km near Livingston and 191/km below the park boundary for cutthroat trout greater than 20 and 24 cm, respectively (Shepard 1992).

Rainbow trout and brown trout occur throughout the Yellowstone River, but are uncommon below the Clarks Fork of the Yellowstone and occur only rarely in the warmwater zone. Between Billings and the Clarks Fork the combined biomass was 6.6 kg/0.3 km in 1984, increasing to a maximum of 103.1 kg/0.3 km near Livingston. Upstream and downstream from Livingston in the salmonid zone, biomass ranged from 32.7 to 48.0 kg/0.3 km (Montana Interagency Stream Fishery Data Base 1992). Based on electrofishing surveys, the trout population (greater than 305 mm long) is dominated by brown trout above Livingston, with densities in 1991 of 254/km, compared with 87/km for rainbow trout and 35/km for cutthroat trout. In the Livingston area rainbow trout were roughly three times (293/km) more abundant than brown trout (103/km) in 1991, while cutthroat trout densities were only 13/km (Shepard 1992).

Mountain whitefish is the most abundant fish of the upper Yellowstone. Large populations occur above the Stillwater River, and they occur in lesser abundance as far downstream as Billings (Table 1). The only biomass estimate in the data base was 315.4 kg/0.3 km in the area above Livingston (Montana Interagency Stream Fishery Data Base 1992). Shepard (1992) reported that numbers have remained relatively constant at from 7,581 to 10,253/km since 1972.

Of the 10 sport fishes that occur in the lower Yellowstone, six provide substantial angling opportunity. Sauger and walleye are highly prized sport fishes of the lower Yellowstone River. Sauger are native to the Yellowstone River and are common to abundant downstream of Billings (rkm 361; Table 1). They were first reported in Montana by the Lewis and Clark expedition (Brown 1971). As with most fishes of the Yellowstone, historic abundance is unknown. Walleye are nonnative, and time of introduction is unknown. They are less abundant than sauger and are more restricted in distribution (Table 1).

Sauger abundance increases and mean length decreases going downstream. Sampling with experimental gill nets (3/4–2-inch square mesh) at five locations between rkm 457 and 114 in September and November 1975, produced an average of 1.92 sauger per net set, ranging from 1.13 at the uppermost site to 3.83 at rkm 298 (Peterman and Haddix 1975). In 40 electrofishing runs made along the lower 553 km of the Yellowstone River, Graham et al. (1979) reported mean number of sauger per 8-km section as 33.6, 23.2 and 15.1 in the lower, middle, and upper areas. Sauger in the upstream area were significantly longer than fishes in the

lower section, owing to a larger proportion of older fishes. Stewart (1986) reported sauger numbers 16 times greater (2,071/km) in the area below Intake Diversion (rkm 114) than at Miles City (rkm 298; 130/km). The number and size of sauger in the Miles City section were essentially unchanged in 1990 (Stewart 1991c). Growth rates were similar in all sections. Tag returns and growth data indicate a general upstream movement of mature sauger after spawning (Graham et al. 1979).

Walleye occur throughout the warmwater zone of the Yellowstone River but are most abundant below Intake Diversion in April and May, when fish migrate upstream from Garrison Reservoir to spawn. Seventy-five percent of the walleye tagged in this area and recaptured the same year were caught downstream in the Missouri River and in upper Garrison Reservoir; average downstream movement was 190 km (71–360 km). In April and May, walleye composed 20–30% of the combined walleye and sauger electrofishing catch. During July they composed only 2% of the combined catch (Haddix and Estes 1976; Graham et al. 1979). Beginning in 1982 this population was used as an egg source by Montana Department of Fish, Wildlife and Parks. In 1989 the population began to decline. Only 60 females were collected in 1989 and 31 in 1990, compared with more than 300 in 1987 and 1988. North Dakota Game and Fish personnel indicate that walleye numbers in upper Garrison Reservoir have declined and are not likely to increase soon (Stewart 1990, 1991c).

Shovelnose sturgeon and pallid sturgeon are native to the warmwater zone of the Yellowstone River. Sturgeon were first classified as sport fishes in 1971. Pallid sturgeon, which weigh up to 27 kg, are the second largest fish in the Yellowstone; they have never been reported to be abundant (Brown 1971). They once ranged throughout the Missouri River and its larger tributaries, as well as the Mississippi River and its large tributaries downstream of the Missouri River confluence. Present distribution and abundance is thought to be dramatically reduced, with only pockets of a few individuals remaining. Pallid sturgeon were listed as endangered in 1990 (U.S. Fish and Wildlife Service 1990a). Threats include habitat modification, hybridization with shovelnose sturgeon, and apparent lack of reproduction. Too few data are available to determine if the pallid sturgeon population in the Yellowstone River has declined.

The documented upstream extent of pallid sturgeon distribution is the mouth of the Tongue River (rkm 298). They have been captured below Intake Diversion Dam (rkm 114), and in 1991 one was captured near Fallon, Montana, at rkm 208 (Watson and Stewart 1991). In 1992 researchers captured one pallid sturgeon in the Yellowstone River just above the Missouri River confluence. Another pallid sturgeon, captured and radio tagged below the confluence, subsequently moved into the lower 6 km of the Yellowstone.

Shovelnose sturgeon are abundant throughout the Yellowstone River downstream of Cartersville Irrigation Diversion Dam (rkm 381). Although precise spawning locations are unknown, shovelnose sturgeon migrate upstream into the Tongue and Powder rivers beginning in late April (Haddix and Estes 1976) and spawn from early June until mid-July (Elser et al. 1977). Ripe females have also been sampled in the mainstem, the largest concentrations being immediately below Intake Diversion Dam.

Yellowstone River shovelnose sturgeon are larger than is reported for most shovelnose sturgeon populations. Average length of 875 shovelnose captured as they moved into the Tongue River during the spring spawning run was 76.4 cm (range 57.1 to 94.8 cm). Average weight was 2.34 kg and ranged from 0.73 to 5.93 kg (Elser et al. 1977). Size of shovelnose sturgeon migrating into the Powder River was similar (mean length 76.1 cm and mean weight 2.42 kg; Rehwinkel 1978). Within the Yellowstone River, average size was larger upstream near Cartersville Diversion (2.8 kg) compared to below Intake Diversion (1 kg; Haddix and Estes 1976). Recent surveys confirm this longitudinal pattern in size distribution (Watson and Stewart 1991). Since small shovelnose sturgeon (less than 0.45 kg) rarely occur above Intake Diversion, principal juvenile rearing habitat is apparently farther downstream.

Paddlefish provide a unique sport fishery in the warmwater zone. A large spawning population from Garrison Reservoir, North Dakota, ascends the Yellowstone during high spring flows. This is one of only five known natural spawning areas within their geographic range (U.S. Fish and Wildlife Service 1990b). Although a paddlefish fishery existed in the early 1900's (Needham 1968), it was essentially unknown to the angling public until 1962, when a Glendive, Montana, fisher, fishing below Intake Diversion Dam snagged what was thought to be an aberrant catch. Within a week, however, 60 more paddlefish were snagged. In 1964 the first intensive population study was initiated

(Robinson 1966). In 1965 the paddlefish was designated as a game fish, and in 1979 it was listed as a state species of special concern (Holton 1980, 1986; Elser 1986).

To reach the most upstream spawning sites, near Forsyth, Montana (rkm 383), paddlefish must first pass a low-head irrigation diversion dam at Intake, Montana (rkm 114). Because the dam is at least a partial barrier, spawners concentrate downstream, making the "snag" fishery more productive there than elsewhere on the Yellowstone (Rehwinkel 1976). Penkal (1981) reported that paddlefish reached the dam in early to late May when water temperatures were 15° C or warmer. Numbers of paddlefish were positively correlated with discharge and suspended sediments. The minimum flow necessary to stimulate upstream movement was estimated to range between 425 and 509 m^3/s. Elser (1973) reported that duration of high flow, as well as the magnitude, was significant in determining extent of upstream migration. In years when discharge increased over a long period, paddlefish migrated farther up the Yellowstone River and remained in the river longer than in years of short duration of increasing flows.

Except for the year of tagging, recapture of tagged paddlefish is highest 3 years after tagging, indicating many fish migrate and spawn every third year (Stewart 1992). Spawning has been documented below Intake Diversion (Penkal 1981; Stewart 1991a, b) and is assumed to occur upstream. In 1990, four ripe females were taken in the fishery at Intake, and three were captured in drifted gill nets between rkm 95 and 103 (Stewart 1991a). Precise spawning locations and characteristics of spawning habitats have not been documented in the Yellowstone River.

In 1989 the Montana State Legislature authorized sale of paddlefish roe from fish legally caught in the sport fishery to the Glendive Chamber of Commerce and Agriculture. The roe is donated by anglers in return for fish processing. In 1991, 1,711 female paddlefish were processed, resulting in 4,841 kg of eggs for a gross income of $292,563 (Stewart 1992). These proceeds are divided equally between Montana Department of Fish, Wildlife and Parks and the Glendive Chamber of Commerce and Agriculture. The Department's share can be used for fishing access improvement, habitat improvement, fisheries management, or providing information to the public regarding fisheries in eastern Montana. Currently, the Department is funding a paddlefish research program with the proceeds. The Chamber's share is designated for historical, cultural, recreational, and fish and wildlife projects. Although no illegal trade of paddlefish roe has been documented in Montana, black market activities have decimated paddlefish populations elsewhere. This potential problem remains a legitimate concern for the paddlefish population of the Yellowstone River.

Channel catfish are one of the most important sport species in the lower Yellowstone River (Haddix and Estes 1976; Elser et al. 1977), yet little is known about the population. They are native to the Yellowstone River drainage and are common to abundant downstream of Huntley Diversion (rkm 566; Table 1). They were first reported by the Lewis and Clark expedition. Haddix and Estes (1976), using experimental gill nets (3/4–2-inch square mesh), sampled fish populations in the lower river. Average catch rates decreased progressively from 7.13/net at rkm 422 to 1.33 at rkm 221. They suggested this may be related to downstream decrease in backwater habitat. Fish ranged from 22.3 to 71.1 cm (mean 42.9 cm) and weighed from 0.09 to 2.9 kg (mean 0.77 kg). Mature channel catfish examined in August 1974 were not yet ripe. Extremely cold water temperatures may have reduced catfish reproduction, and Haddix and Estes speculated that, in some years, suitable spawning temperatures are reached only in backwaters, side channels, and tributaries. Elser et al. (1977) reported that 44% of returns from channel catfish tagged in the Tongue River were from the Yellowstone River. One fish was taken at the Yellowstone–Missouri River confluence, about 303 km downstream from where it was tagged.

Burbot are native to Montana. They are abundant downstream of Billings, but occur as far upstream as Springdale (Montana Interagency Stream Fishery Data Base 1992; Table 1). Angling for burbot is popular in late winter and early spring below irrigation structures and at tributary mouths. Burbot was designated as a game fish in 1975 (Haddix and Estes 1976). Only two population estimates have been reported (Poore and Darling 1989). In an 8.8 km sampling section immediately upstream of Laurel, Montana (rkm 615), the burbot population was estimated to be 55/km in fall 1987 and 65/km in fall 1988. Length ranged from 23 to 92 cm. Haddix and Estes (1976) reported age of burbot in the catch, as determined from otoliths, ranged from 4 to 11 years. Average annual growth was 3.6 cm. Cursory food habit analysis revealed that the primary prey were longnose dace, flathead

chub, and juvenile burbot. All 93 fish examined in the February–March creel census had already spawned. Although 60 fish were tagged, none was recaptured (Haddix and Estes 1976).

Sport Fishery Harvest, Use, and Regulations

Fishing pressure in the Yellowstone River is greatest in the coldwater zone. The highest fishing pressure is in Yellowstone National Park. Restrictive regulations in the Yellowstone River between Upper Falls and Yellowstone Lake have become necessary, despite pristine habitat conditions and absence of introduced trout species. This 14-km reach supports one of the most intensively fished native trout populations in North America. From the 1950's through 1972, angler effort averaged 88,000 h/year but then declined to 57,000 h/year during the first 2 years of catch-and-release regulations. Since 1974, however, angler effort has again increased, averaging 127,000 h/year since 1987 (Jones et al. 1992). This is equivalent to 1,257 angler-hours per hectare per year. Schill et al. (1986) found that cutthroat trout in a portion of this area were captured an average of 9.7 times during a 108-day season. They reported fishing mortality of only about 3%. The fishery has been popular since Jordan (1891) and Evermann (1892) reported that trout in this reach were abundant. The creel limit was 20 trout during the 1920's, 10 during the 1930's, 5 between 1949 and 1953, and 3 from 1953 to 1973, when catch-and-release regulations were implemented (Jones et al. 1992).

Downstream of Yellowstone National Park, sportfishing regulations were first implemented in Montana in 1938. The creel limit for all sport fishes combined was 25 fishes, not to exceed 20 lb and 1 fish, with no more than 5 fishes under 7 inches. From 1939 to 1946 the limit was 15 fish. Since then regulations have become progressively more complex and restrictive for several species.

The first specific limit on trout was 15, not to exceed 10 lb and one fish, imposed in 1947. From 1955 to 1978 there was a 10 trout or 10 lb plus one fish limit, with a few slight variations. In 1978, the creel limit was reduced to five trout with only one greater than 18 inches. Except for the 1984 implementation of catch-and-release regulations on Yellowstone cutthroat trout and a slot limit and gear restrictions in the upper river for brown trout and rainbow trout, this creel limit remains in place today. The mountain whitefish creel limit has increased from 15 in 1953 to 100 beginning in 1985.

From 1942 to 1949 the catfish limit was 15 fish not to exceed 15 lb and 1 fish. Since then there has been no limit, and in 1962 hoopnets without leads were legalized downstream of Intake, and in 1981 downstream of the Bighorn River. There has never been a limit on burbot or sturgeon. Adult pallid sturgeon have been protected by a 7.3-kg maximum weight limit for creeled sturgeon since 1980. The combined limit for sauger and walleye was 15 fish or 15 lb and 1 fish from 1947 to 1974; minimum lengths were 10 or 12 inches. From 1975 to 1992, the limit has been 10 fish with no additional restriction. The first creel limit for paddlefish (1965) in the lower Yellowstone River was two fish with four in possession. In 1968, the possession limit was reduced to two fish. In 1979, the daily limit was reduced to one fish with two in possession. Because of the increasing popularity of the fishery, a two-fish annual limit was imposed in 1983. The limit on bass has ranged from no limit to 15, to the present 5.

Downstream of Yellowstone National Park, fishing pressure ranged from 179.4 days/km to 527.0 days/km with the greatest pressure upstream of the Shields River (rkm 787; Montana Interagency Stream Fishery Data Base 1992). Use in this upstream area increased from 31,908 angler-days in 1983 to 34,556 angler-days in 1985 (Shepard 1992). The only intensive creel survey of the upper Yellowstone showed use at 429 h/km and harvest at 106 trout/km from 22 March to 19 September 1982 (Javorsky 1984). Berg (1975) estimated fishing pressures of 266–318 h/km upstream and 919–998 h/km downstream from Livingston (rkm 796).

Numbers of cutthroat trout larger than 305 mm in the upper Yellowstone River have more than doubled since 1984, when catch-and-release regulations were implemented, but there has been no documented increase in abundance of large (greater than 406 mm) cutthroat trout. Brown trout responded well to the slot limit, but numbers of mid-sized (330–406 mm) rainbow trout and cutthroat trout seemed to be depressed (Clancy 1987; Shepard 1992).

From the Shields River (rkm 787) downstream to Billings (rkm 580), use varied from 381.6 days/km to 174.4 days/km. Downstream, between Billings and Intake Diversion (rkm 114), fishing pressure was much less (17.3–22.1 days/km). Below Intake use increased to an estimated

133.5 days/km (Montana Interagency Stream Fishery Data Base 1992), primarily because of the paddlefish fishery.

The most complete use and harvest information for the Montana section of the Yellowstone River is for paddlefish. Because this fishery is concentrated immediately below Intake Diversion Dam, harvest and use can be readily monitored. Based on 18 years of creel data, angler-days have ranged from 2,118 in 1972 to 6,130 in 1978; in 1991 effort was 3,332 days. The catch rate ranged from 550 (0.34 fish/angler-day) in 1985 to 5,318 (1.33 fish/angler-day) in 1981. Maximum catch rate was 1.91/angler-day in 1973. In 1991 the catch was 4,203 and catch rate was 1.19 fish/angler-day. Total weight harvested was 85,792 kg in 1991 and has ranged from 11,775 kg in 1985 to 112,607 kg in 1981. Male paddlefish weighed an average of 11.3 kg and females 17.4 kg (Table 2; Stewart 1992).

Of the 5,990 paddlefish tagged at Intake Diversion and downstream points since 1964, a minimum of 1,389 (22.5%) have been harvested by anglers (Stewart 1992). Of 49 tags returned in 1991, 14 had been tagged in 1984 and 11 in 1988; one fish had been tagged in 1965. Mean minimum annual exploitation rates for paddlefish tagged in 1984, 1986, 1988, and 1990 ranged from 3.3% to 8.4% (Table 3; Stewart 1992). Actual exploitation rate could be as high as 10%, which is not considered to be overharvest (Pash and Alexander 1986). Whatever the true exploitation rate, no evidence of overharvest has been seen. Size of males has remained stable for the past 10 years, and average size of females may be increasing (Table 2). Recruitment, based on small size classes in the catch, seems to be stable or increasing (Stewart 1992).

Little information is available on exploitation rate of other sport fishes of the lower Yellowstone River. Based on tag returns, Peterman and Haddix (1975) reported a minimum sauger harvest of 6%; Graham et al. (1979) reported a minimum harvest of walleye and sauger of 5.0%. More recently, Stewart (1990) estimated 5.9% angling mortality for 615 sauger and walleye, based on 36 first-year tag returns. He noted that this is a minimum estimate, but even if mortality is twice that calculated it is still within acceptable limits of 25–30%.

Fishing pressure for shovelnose sturgeon is light, although it is a popular sport fish for local anglers on the lower Yellowstone. Elser et al. (1977) reported a tag return rate for only 1.1% of 1,890 adult shovelnose tagged between 1974 and 1976. Tags from these fish are still being recovered, 18 years later (P. A. Stewart, Montana Department of Fish, Wildlife and Parks, Helena, personal communication).

Burbot and channel catfish are also popular with local anglers, but exploitation rate is low. A creel census in February and March 1975 below Cartersville Diversion showed an overall catch rate of 1.77 burbot per angler-hour. Catch rates ranged from 0.68/h to 5.6/h (Haddix and Estes 1976). Of 527 burbot tagged in the transition zone since 1978, 7% have been reported caught (M. Vaughn, Montana Department of Fish, Wildlife and Parks, Billings, personal communication). The only known information available on the channel catfish fishery is based on creel checks by wardens, which accounted for about 25% of the catch in the lower river in the early 1970's (Haddix and Estes 1976).

Human Effects on the Fishery

The Yellowstone River, although relatively pristine by comparison with most large rivers in the continental United States, is not without human-induced biological and physical effects. Human activities have modified channel morphology only modestly (Silverman and Tomlinsen 1984). Much of the river is essentially unchanged from when William Clark first explored the Yellowstone in 1806. Koch et al. (1977) reported that channel characteristics had not changed markedly in 180 years. Although not extensive, riprapping, closing side channels, and clearing riparian vegetation have affected channel characteristics locally. Downstream from the confluence of the Bighorn River, the Yellowstone may be narrowing and deepening because of modification of sediment dynamics resulting from Yellowtail and Tongue River dams, but cause and effect relationships have not been demonstrated. Low-flow augmentation from Bighorn Reservoir has increased flow in the lower Yellowstone River during low-flow periods (Engineering Consultants, Inc. 1978).

Although human influences have had some impact on channel characteristics in the Yellowstone River, the principal known effects on fish populations are associated with water withdrawal for agricultural purposes. About 90% of all water use in the Yellowstone basin is for irrigation; in 1981 this amounted to 1.5 million acre-feet (Department of Natural Resources and Conservation 1981) and has not increased substantially since then.

Table 2. Summary of paddlefish average eye-to-fork length (E–F) and weight, by sex, obtained from the angler catch at Intake, Yellowstone River, 1963–91 (from Stewart 1992).

	Males			Females		
Year	Sample size	Length (E–F, mm)	Weight (kg)	Sample size	Length (E–F, mm)	Weight (kg)
1963	46		13.4			
1964	28		9.6			
1967	123		9.9			
1968				6		19.2
1970	620		11.9			
1971	620		11.7	516		23.9
1972	869		10.7	809		24.2
1974	932		11.1	978		25.1
1976	303		11.7	637		27.3
1978	259		13.6	550		29.9
1979	207		11.3	430		27.9
1981	630	954	12.6	1,898	1,130	24.0
1982	577	937	11.1	1,427	1,138	24.4
1983	244	932	11.7	1,156	1,117	25.1
1984	832	954	10.9	1,859	1,136	24.0
1985	134	914	11.0	494	1,134	24.2
1986	537	932	11.2	925	1,142	24.8
1987	322	916	11.6	1,090	1,143	25.8
1988	695	929	11.6	1,085	1,141	24.9
1989	475	931	11.2	1,108	1,150	25.8
1990	516	922	10.8	977	1,153	25.9
1991	1,080	916	11.3	1,462	1,159	27.4

In the upper Yellowstone River, Yellowstone cutthroat trout spawn in tributary streams from May through mid-July (Clancy 1988) and exhibit strong homing tendencies to return to natal streams (Benson 1960; Hadley 1984; Varley and Gresswell 1988; Leary et al. 1989). Dewatering of essential spawning habitat seems to be the most important factor influencing the present population (Berg 1975; Hadley 1984; Clancy 1988; Byorth 1990). Water diversion for irrigation begins during spring runoff and continues through early fall, which corresponds to the reproductive cycle of the cutthroat trout. Berg (1975) found that 94 km of tributary streams were dry or severely dewatered during peak irrigation in 1974 and 55 km in 1975. Only seven tributaries of the Yellowstone River in Montana support successful spawning runs (Clancy 1988), compared with nine tributaries in 1975 (Berg 1975). Distribution of high quality spawning tributaries seems to relate directly to level of recruitment into the Yellowstone River. Numbers of 2-year-old and older Yellowstone cutthroat trout were highest in sections of river with high quality tributaries and stable flows (Clancy 1988).

Byorth (1990) evaluated how existing levels of dewatering affected fry production in two spawning tributaries. In a dry year, 21% of the redds were dewatered in Cedar Creek, while the lower segment of Big Creek was completely dry from early July to mid-October because of irrigation diversion. In some tributaries in low-water years, adults either do not spawn or leave before completing spawning as flows become inadequate (Clancy 1988).

Other perturbations include over-grazing, sedimentation, and barriers (e.g., culverts) to spawning migrations. In combination, water diversion and habitat modifications have resulted in a decline in cutthroat trout abundance and thus a reduced capacity of the population to sustain angler harvest, making restrictive angling regulations necessary (Clancy 1988).

Water diversion structures in the lower Yellowstone River are known to influence upstream movement of paddlefish, shovelnose sturgeon, sauger, and walleye. Most other species would probably have difficulty passing upstream of the structures as well.

Two of the three major in-channel diversion structures, downstream of Billings, have been

evaluated for sport fish passage. Cartersville Diversión is located at rkm 382, and Intake Diversion is located at rkm 114. Cartersville Diversion is a concrete structure spanning the entire 230-m width of the channel. During intermediate to low flows, the structure creates a vertical drop of about 0.5 m. During high spring flows and when ice jams form below the diversion, the difference in downstream water elevation is less pronounced (Graham et al. 1979).

Intake Diversion extends the 219 m width of the channel. A side channel, which bypasses Intake to the south, begins to flow at a discharge of 650 m^3/s. The diversion consists of a wood, stone, and steel apron over which boulders are periodically placed to maintain adequate head. The diversion forms a turbulent cascade with a drop of about 1.2 m in 30 m (Graham et al. 1979; Peterman 1980).

Paddlefish move upstream of Intake Diversion only during years of above-average May–June flow (Stewart 1992); they are not known to pass Cartersville Diversion. Substantial passage does not occur at flows less than 1,274 m^3/s (Peterman 1979). In 1990, when peak flow was 1,036 m^3/s, no paddlefish were sampled above Intake (Stewart 1991a). Paddlefish are known to use the side-channel during high-flow years, but it is not known if they also negotiate the diversion during these conditions (Stewart 1992). Passing the diversion provides an additional 276 km of potential spawning area (Peterman 1980).

Haddix and Estes (1976) and Stewart (1990) found shovelnose sturgeon below but not above Cartersville Diversion, indicating that this structure is an upstream barrier to migration. Longtime residents of the area reported that shovelnose sturgeon were common above the diversion site before the dam was built. Although no studies of shovelnose sturgeon passage at Intake have been conducted, two radio-tagged fish moved over the diversion during below-average 1992 spring flows (P. Clancey, Montana Department of Fish, Wildlife and Parks, personal communication).

Effects of the Cartersville and Intake diversion structures on fish movement were evaluated by tagging 2,573 sauger and 697 walleye from 1973 to 1977. Fifty-one walleye and 195 sauger were recaptured. Movement of both species out of the Intake area was extensive following spawning. Although walleye could negotiate the structure, the migratory Garrison Reservoir population spawned just below Intake, and nearly all movement was downstream following spawning (Graham et al. 1979).

Sauger tagged downstream of Intake Diversion also moved extensively, but most (57%) moved upstream. Average movement of the 33% that moved downstream was 172 km (13–417 km); two fish were recaptured in the Missouri River 58 and 304 km upstream from the Yellowstone River confluence. Average upstream movement above Intake was 203 km (129–269 km; Graham et al. 1977).

Although some sauger negotiated Cartersville Diversion, migration seemed to be restricted by the dam; of 195 tag returns, only 9 were from above the dam (Graham et al. 1979). Stewart (1990) reported sauger densities were 7.2 times greater downstream of the dam than upstream (18/km above and 130/km below). Of 540 sauger tagged below the dam in 1985, 1987, and 1988, only 1 of 49 tag returns was from above the dam.

Table 3. Annual angler exploitation rates of Garrison Reservoir paddlefish as indicated by tag returns (from Stewart 1992).

	Year tagged [number of fish tagged]							
Year recaptured	1984	[551]	1986	[153]	1988	[156]	1990	[153]
1984	73	(13.2)[a]						
1985	2	(0.4)						
1986	33	(6.9)	9	(5.9)				
1987	42	(9.5)	0	(0.0)				
1988	13	(3.2)	7	(4.9)	22	(14.1)		
1989	19	(4.9)	7	(5.1)	3	(2.2)		
1990	21	(5.7)	4	(3.1)	8	(6.1)	6	(3.9)
1991	11	(3.1)	7	(5.5)	14	(11.4)	4	(2.7)
Average		(5.9)		(4.1)		(8.4)		(3.3)

[a] Column entries represent the number and percent (in parentheses) of recapture in the noted years. Percent recaptured was calculated as follows:

$$\text{Percent recaptured} = \frac{\text{number caught that year}}{\text{number tagged} - \text{number caught in previous years}}.$$

Cartersville Diversion is more of a physical barrier than Intake because of the 0.5-m vertical drop at summer discharges.

Preservation of the River and Its Fisheries

The Yellowstone River has faced the same threats as other large rivers, but unlike most it has remained relatively unaltered by human activities. As early as 1902 dam-builders identified a site upstream of Livingston, Montana, in Paradise Valley as a suitable place to impound the Yellowstone (Schneider 1985). The Allenspur Dam project has surfaced repeatedly since, but it has not received public support.

A partial solution to the Nation's energy crisis of the early 1970's was major development of Montana's huge coal reserves. Twenty-one coal-fired generating plants were proposed. The only source of cooling water was from the Yellowstone River basin. The Montana-Wyoming Aqueducts would divert 2.6 million acre-feet into the Fort Union coal fields, one-third of the river's flow (Posewitz 1979; Schneider 1985). Because of these and other industrial threats, in 1974 the Montana Legislature implemented a 3-year moratorium on water filings over 0.6 m^3/s in the Yellowstone basin.

Fortuitously, in 1973, the Montana Water Use Act had been passed. This legislation replaced a water use system that virtually guaranteed depletion of rivers with one that allowed instream flow advocates to compete with consumptive users for unreserved water. The concept of reserving waters for future beneficial uses and instream values was a significant departure from traditional western water law (Peterman 1979; Schneider 1985).

The moratorium on water filings emphasized the need for reserving water in the Yellowstone basin for the protection of existing and future beneficial uses. Particular attention was given to reserving water for municipal and agricultural needs, as well as guaranteeing minimum instream flows for protecting aquatic life, water quality, and existing water rights (Peterman 1979). After 2 years of study, the Montana Department of Fish and Game applied for 8.2 million acre-feet of flow at Sidney, Montana (rkm 47; Peterman 1979; Posewitz 1979). After an evaluation of all competing applications for reservation of Yellowstone basin water, Montana Department of Fish and Game was granted 5.5 million acre-feet of water at Sidney in December 1978. The quantity of water granted varies monthly and follows the shape of the natural hydrograph. The flow granted can be expected to be equalled or exceeded about 85 years out of 100 (Peterman 1979).

Allocation of minimum flows in the Yellowstone basin should prevent future depletions from further affecting the aquatic ecosystem during low-water years. Since Montana water law prioritizes water rights on a first in time, first in right basis, the guarantee of minimum instream flow throughout the basin benefits holders of prior water rights by ensuring that the source of supply for their water is not severely depleted. Future water users not covered under the reservation (primarily industry) will be forced to apply water conservation measures or supply on-site storage facilities to be assured of a constant water supply. The successful implementation of the granted instream flows in the Yellowstone may help ensure its continuance as the Nation's longest free-flowing river (Peterman 1979, 1980).

Although the Yellowstone River currently enjoys a significant measure of protection for its aquatic and riparian communities, the protection is neither absolute nor for all time. The reservation is subject to appeal through the courts. Also, the reservations must be reviewed at least once every 10 years and may be modified by the Board of Natural Resources during the review process. While not necessarily the final word, the reservations on the Yellowstone set a precedent for future instream flow considerations and the development of a river ethic (Peterman 1980).

More recently (1989, ammended in 1991) the Montana Legislature passed legislation (HB 707) on water leasing for instream flow. The issue arose as a result of the 1988 drought and a recommendation of the state water plan. The purpose of the bill is to study the feasibility of leasing existing water rights to maintain or enhance streamflow for fisheries. The bill established a pilot program that allows the Department of Fish, Wildlife and Parks to lease water rights from willing individuals and groups. Up to 10 stream reaches may be leased for up to 10 years upon approval of the Board of Natural Resources and Conservation. The maximum quantity of water that may be leased is the amount historically diverted by the lessor. Only an amount of water equal to or less than that historically consumed may be used to maintain or enhance streamflows below the lessor's point of diversion.

The first and possibly the first three water leases in this program will be on tributaries of upper Yellowstone River. Increased instream flow will increase the amount of Yellowstone cutthroat trout spawning habitat and subsequent recruitment. If this program is successful, it will greatly benefit streams that are presently dewatered, as well as serve as a model for instream flow enhancement elsewhere.

In addition to instream flow protection and enhancement, modification of Cartersville Diversion Dam to improve fish passage is currently being considered. Funding has been requested through the River Restoration Act of 1989 (Stewart 1990). Also, the renovation of the Huntly Diversion Dam, proposed by the U.S. Bureau of Reclamation, would include a fish ladder (J. Darling, Montana Department of Fish, Wildlife and Parks, Billings, personal communication).

The Yellowstone River is among the last remaining, relatively unaltered large rivers in the continental United States. This resource, important in its own right, will be key to understanding how large western rivers function, and subsequently to mitigation efforts in the Missouri River basin. Protection of this unique system will require diligence on the part of the public and resource agencies. If past history is any indication, the future of the Yellowstone River is bright.

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Sediment Imbalance in Rivers: Simulation Possibilities and Problems

by

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Abstract. River engineering, having begun the 20th century as a well-intentioned but naive determination to tame and capture nature's water resources, is approaching the 21st century with a sober realization of the complexity and consequences of disturbances to a river's natural equilibrium and its ecosystem. This coming-of-age, born of extensive and sometimes painful experience in rivers' long-term response to man's intervention, has been accompanied, indeed nurtured, by new capabilities in computer-based simulation of nonequilibrium fluvial processes. If it is clear that today's simulation techniques may have led to more careful and successful river engineering in the past, it is not so clear that simulation provides, in itself, a tool of sufficient reliability to guide future river engineering and development. This is a result of our continuing feeble understanding of some of the most complex physical processes known to man, and also of our tendency to place too much confidence in these first-generation simulation models and in their practitioners. We describe the common bases of most nonequilibrium simulation models, assess the strengths and future possibilities of such models in providing technical support for river-development decisions, and present an example of application to the Missouri River. The value of models to provide insight into river response, if not finite answers, is illustrated through application of a numerical model to the Missouri River.

Alluvial rivers—those that convey not only water and living organisms, but also the sediments composing their bed and banks—are among the most complex natural systems dealt with by engineers. Alluvial rivers are architects of their own geometry, shaping and molding their channels and their planform meanders, in transporting their imposed water and sediment loads from the watershed to the sea while providing habitat for living organisms.

The notion of an equilibrium between the channel and planform geometry on one hand, and the imposed water and sediment loads on the other, depends very much on the time scale of interest. At any given moment, or indeed in any given year or perhaps decade, the channel and planform geometry—and thus the riverine habitat—are continually changing in response to short-term floods or droughts, watershed and land-use changes, and perhaps even seismic topographic adjustments. At a much larger time scale, of the order of decades or centuries, a river's channel and planform geometry, and the size of transported sediments, reflect an equilibrium between the water and sediment loads entering the river from the watershed and the river's capacity to convey these loads. This dynamic equilibrium implies a certain equilibrium habitat, at least insofar as bed and bank geometry, bed and bank vegetation, and suspended sediment are concerned.

Now enter man, also known as the river engineer. In straightening channels through artificial cutoffs, blocking sediment transport with dams, stabilizing banks, building river-training structures for navigation, paving the watershed, diverting tributaries, and so forth, man imposes drastic

changes on a river and its ecosystem, and generally in a very short time (months to years). But the response of the river and its ecosystem to these perturbations is not necessarily correspondingly short. Several decades, perhaps even centuries, may be required before the river returns to a new (or former) equilibrium channel and planform geometry. Ironically, such natural response times often span at least the typical professional career of a river engineer. Yet this seemingly slow response may, in just one generation, exterminate a species that has otherwise survived from the age of the dinosaurs.

Nature's deliberate but definite response to man's rapid (and equally definite) intervention may deprive the river engineer of an immediate-feedback mechanism for evaluating the effectiveness (and indirect habitat effects) of engineering works. Design evaluations thus have relied on physical scale-model studies for local, rather short-term effects. Yet the scaling of physical models can be inaccurate, especially when extended lengths of river or periods of time are modeled. For this reason, and because of the inordinate physical size of laboratory space required, it rarely has been practical to use physical models for those situations.

Computational simulation of extended lengths of rivers and periods of time began in the 1960's. At that time fixed-bed computational modelling (that is, numerical simulation of flood propagation and backwater effects in immobile-bed channels) began to achieve a certain engineering maturity, and the next logical step was to apply the same techniques to mobile-bed simulation. However, whereas fixed-bed modelling evolved into a reliable, mature engineering tool in the space of about 10 years, mobile-bed modelling is still in its infancy, groping for the status of its fixed-bed progenitor.

The problem in mobile-bed computational modelling is one of applying effective numerical techniques to frustratingly limited, crude schematizations of complex water-sediment processes, with the goal of making reliable long-term predictions of a river's response to changes imposed upon it. That some progress has been made toward this goal is a tribute more to the skill, intuition, and experience of numerical modelers than to any inherent reliability of the modelling techniques employed.

In the remainder of this paper we provide a brief overview of mobile-bed computational modelling, discuss challenges and opportunities for the future, and present an example application to the Missouri River. Our purpose is to provide general background on the capabilities and limitations of such modelling in support of river-development decisions.

Sediment Non-equilibrium

An early recognition of the notion of the mechanisms by which an alluvial river is always trying to achieve an equilibrium was presented by Lane (1957) and depicted in a classic diagram, a recent version of which is shown in Fig. 1. The diagram reflects the essential role of shear stress exerted on a river bed by flowing water and relates the sediment transport to the flow hydraulics. On the water side of the scale, bed shear stress increases as the channel slope and water discharge increase. On the sediment side of the scale, the amount of sediment transported increases with the shear stress, and finer sediment is more easily transported than coarser sediment. Thus excessive or insufficient shear (with regard to equilibrium conditions) results in degradation (scour) or aggradation (deposition) toward a new equilibrium, or balance. This can result from adjustments of sediment load, sediment size, channel slope (as in planform meandering), or channel cross section (not explicitly represented in the diagram). Of course even natural rivers are seldom in a state of true equilibrium, but rather are constantly adjusting. The balances of Fig. 1 reflect both natural and perturbed adjustment tendencies.

The qualitative understanding of the processes represented in Fig. 1 has entered the river-engineering lexicon through the term "hungry water," referring to the inevitable bed scour and degradation immediately downstream of dams that trap sediments, releasing clear water with its potential for unmitigated scour.

Figure 1 is thought-provoking and summarizes the essential features of dynamic river equilibrium. However, there are complexities and subtleties in the way equilibrium can be obtained. For example, hydraulic sorting, that is, the preferential transport of finer material in a mixture, can result in a coarsening of the bed; indeed, this is the essential process by which the sediment-size adjustments of Fig. 1 occur. But accumulation of a relatively small amount of coarse, nonmoving material in an interlocking pattern on the bed can suppress virtually

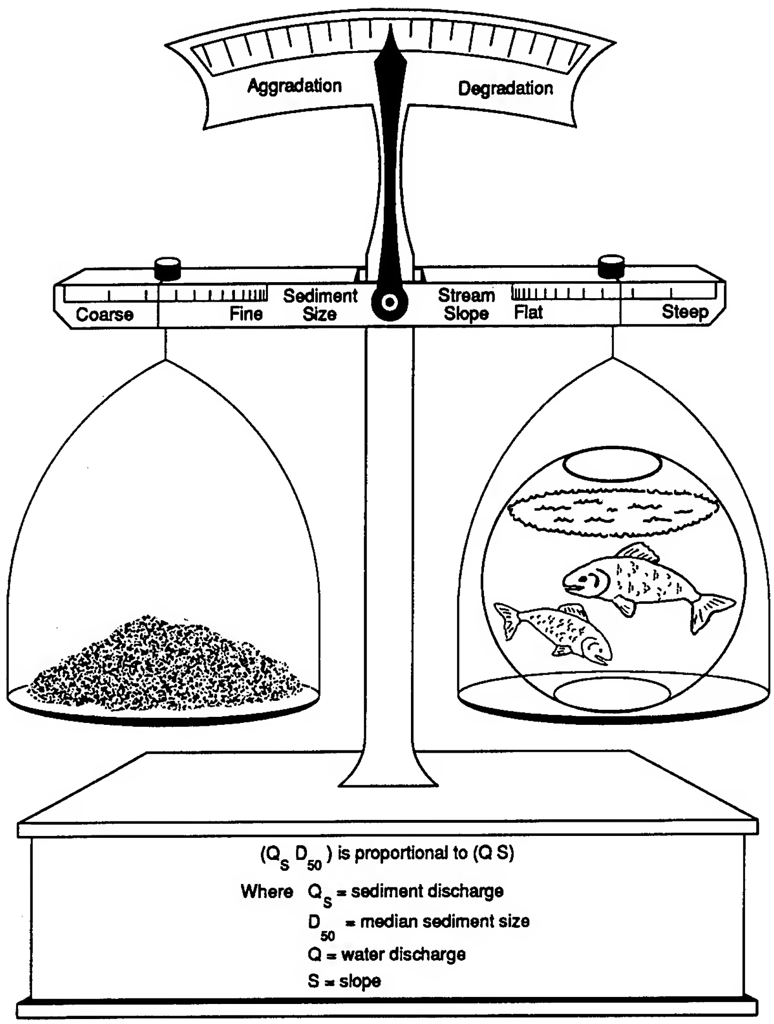

Fig. 1. Schematic of the Lane relationship for qualitative analysis (Simons and Li Associates 1982).

all sediment movement on the bed (Harrison 1950). This so-called armoring or paving phenomenon can be an essential mechanism for return toward equilibrium from a perturbed state.

A subtlety not explicitly shown in Fig. 1 is the macro-texture of the bed, that is, the existence of bedforms such as dunes, ripples, and antidunes. These features, whose existence reflects a balance among shear stress, sediment size, and free-surface conditions (Simons and Richardson 1966), effectively allow a channel bed to adjust its large-scale roughness to the prevailing hydraulic and sediment conditions. Sediment-transport capacity and large-scale channel roughness are intimately related (Karim and Kennedy 1982).

A channel cannot grossly adjust its overall longitudinal valley slope, as this is essentially fixed by the geologic landform topography and sediment provenance. In altering its channel form, for example by meandering around the flood plain, it can effectively adjust its length and thereby its local slope as implied on the water side of Fig. 1. Meandering, though, can only occur through bank erosion, which in turn depends on the erodibility of the banks. This erodibility depends strongly on the mechanical nature of the bank material, and also on its vegetative cover. In addition, local or massive rock outcrops can limit bank erodibility, and thus constrain a river reach.

Figure 1 is implicitly limited to consideration of so-called bed-material sediment load, that is, to the situation in which any sediment in active transport is represented in the bed, either on the surface or immediately below it. However, there may be additional sediment in transport that has no interaction with the bed and is not represented in it; this is often called washload. A typical situation is one in which an upstream event, such as flushing of a reservoir or a storm on a watershed, causes a large amount of fine material—material

finer than that found on the bed—to enter the river. Such material will generally remain in suspension, traveling downstream at the water velocity, until it reaches a point where the prevailing shear stress is low enough that it settles persistently to the bed and begins to interact with it. This transport mechanism, called suspended-load transport, can also occur for sediments eroded from the bed in an area of high shear stress; the significance of it is that sediment particles travel downstream essentially at the same speed as the water, that is, at the order of 1 m/s. By contrast, bedload transport, by which material travels downstream very near the bed by rolling, sliding, and making short hops in response to turbulent flow fluctuations, carries sediment downstream very slowly in comparison with the speed of water movement, at speeds of the order of several kilometers per year. Indeed, the essential mechanism for downstream movement of bedload is intermittent local deposition, whereby increased velocity causes the shear stress to increase sufficiently to re-entrain the sediment and move it on down a bit farther, and so on.

Anyone who has walked along exposed portions of a river bed knows that there can be a remarkable heterogeneity of bed sediment in a particular location. Yet Fig. 1 indicates that there is a single slope, a single sediment load and size, and so forth. A key feature of a river's nonequilibrium response to perturbations can be spatial redistribution of bed sediment, bedforms, and even subchannels within the overall waterway in a braided system. The nonequilibrium response of meandering channels is typically characterized by spatial and temporal redistribution of geomorphic features.

Thus, while the essential features of a river's response to perturbed equilibrium are conceptually summarized in Fig. 1, there are many other subtle features of the response that are poorly understood at best, and in any case not amenable to direct analysis. One example is the dependence of viscosity on temperature, which leads to major changes in suspended-sediment transport, as well as bedform change and consequent dramatic rating-curve shifts on the Missouri River. The goal of numerical simulation of mobile-bed processes is to provide effective prediction of nonequilibrium river response by bringing together the best possible conceptual mathematical models of the important processes, and solving the resulting systems of equations using appropriate numerical methods.

Basis for Computer Simulation

Many investigators are involved in developing mobile-bed computational models. Such models can differ at several levels, from the gross to the subtle. The grossest distinction is in dimensionality.

Nature is three-dimensional (3-D), and ideally one should construct mobile-bed simulation models on the basis of a full 3-D description of the water and sediment processes. Until recently, however, the sheer computer-resource demands have precluded serious development of 3-D mobile-bed simulation codes. At present, the Iowa Institute of Hydraulic Research is working with the U.S. Army Corps of Engineers Waterways Experiment Station to implement mobile-bed processes in the existing Computational Hydraulics 3-Dimensional (CH3D) 3-D fixed-bed hydrodynamic code for natural waterways.

Two-dimensional (2-D) simulation can be focused on width-averaged processes, or depth-averaged ones. Width-averaged analysis is often used to study mechanisms of sediment exchange between the bed and the water column, see for example van Rijn (1984). The depth-averaged (plan-view) simulation generally used for analysis of natural waterways and reservoirs is often justified when stratification effects are weak. A depth-averaged representation allows the spatial heterogeneity of bed sediment and geometry to be recognized, but at the price of significant demands on computer resources. The U.S. Army Corps of Engineers TABS-2 system (Thomas and McAnally 1985) has been in active use in the last decade. This model is limited to a single sediment size class and only the suspended-load mode of sediment transport. The MOBED2 system, recently developed at the Iowa Institute of Hydraulic Research by Spasojevic (Spasojevic and Holly 1990), treats suspended-load and bedload transport of sediment mixtures, and has been successfully used for simulation of reservoir sedimentation.

One-dimensional (1-D) models deal with cross-sectional average channel and flow properties, including bed sediment. They are incapable of recognizing the spatial heterogeneity of bed sediments, local channelization, and so forth. But to the extent that they enable the river engineer to study the response of a simple 1-D system having certain macroscopic properties in common with the real river under study, they can be useful tools within their limits of applicability, especially because

they are not particularly demanding of computer resources. A recent workshop conducted by the Federal Energy Regulatory Commission (Fan 1988) provided a comprehensive review of most of the codes in active use or in development.

The various 1-D models represent quite different conceptions of the physical processes of sorting and armoring, selective transport of sediment mixtures, channel width adjustments, and flow hydrodynamics. In addition, they differ significantly in the numerical techniques employed to obtain approximate solutions to the nonlinear governing equations. At present, there does not seem to be one model, or family of models, that is best in the sense of incorporating the most complete description of 1-D mobile-bed physical processes. Rather, each model tends to focus on the particular process judged most important by the model developer. For example, one code may carry the distinction between bedload and suspended load to a high level of refinement, assuming nonerodible banks, whereas another code may treat bedload and suspended-load distinctions with a great deal less care but adopt a highly refined procedure for channel width adjustment through bank erosion.

The remainder of this section and the example Missouri River application that follows are focused on a particular 1-D mobile-bed simulation code, CHARIMA (Holly et al. 1990).

The central feature of any 1-D mobile-bed model is the so-called Exner equation, expressing conservation of sediment in a control volume of the river bed, as follows:

$$(1-p)\,B\frac{\partial z}{\partial t}+\frac{\partial Q_s}{\partial x}+S=0 \qquad (1)$$

where p = bed-sediment porosity, B = bed width subject to erosion or deposition, z = average bed elevation, Q_s = bedload transport, S = suspended-load source exchange between the bed and the water column, t = time, and x = longitudinal (streamwise) length coordinate. Equation 1 simply formalizes the fact that any net bedload or suspended-load inflow into the control volume across its control surface must result in a net increase of sediment material in the control volume, and this must cause a change in the bed elevation (erosion or deposition).

If Equation 1 were considered as the pillar of a mobile-bed model, the rest of the model can be considered as providing the wherewithal for Equation 1 to do its job. The bedload transport, Q_s, depends strongly and nonlinearly on the flow hydrodynamics, through the depth and velocity (discharge). Thus a parallel hydraulic computation solves the de St. Venant equations for unsteady flow, expressing conservation of mass and momentum:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \qquad (2)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}(\alpha\frac{Q^2}{A})+gA\frac{\partial y}{\partial x}+gA\frac{Q\mid Q\mid}{K^2}=0 \qquad (3)$$

where A = cross-sectional flow area, Q = water discharge, α = kinetic-energy correction coefficient, g = gravitational acceleration, y = water-surface elevation, and K = channel conveyance. The dependent variables of these flow equations are the water discharge (Q) and water-surface elevation (y), both varying spatially and temporally.

The bedload transport (Q_s) and the erosion component of the suspended-load source term (S) of Equation 1 depend not only on the flow conditions, but also on the bed composition, that is, the representation of various grain sizes, discretized as size classes, in the exposed material on the bed and available for entrainment. The tracking of changes in the bed-material composition requires solution of several so-called sorting equations, similar to Equation 1 but expressing mass conservation for each of several sediment size classes in a layer of active bed-sediment mixing near the bed.

Sediment in suspended-load transport obeys a mass-conservation law written for a control volume that includes the water column. This advection-diffusion equation is written for each size class as

$$\frac{\partial}{\partial_t}(C_jA)+\frac{\partial}{\partial_x}(C_jQ)=\frac{\partial}{\partial_x}(AK\frac{\partial C_j}{\partial_x})+S_j \qquad (4)$$

where C_j = section-averaged suspended-load concentration for a size class j, K = diffusion coefficient, and S_j = the source-term exchange of sediment between the bed and the water column that appears in Equation 1; it also appears in the sorting equations for each size class. Note that the source term in Equation 1 actually represents the sum of source terms over all size classes in the model. This source depends strongly and nonlinearly on the local hydraulic conditions, the bed-sediment and suspended-load composition, and the actual suspended-load concentration itself.

These basic relations, all feeding Equation 1, are supplemented by additional ones representing bed armoring, transport-dependent bed roughness, channel geometry, bank erosion, and, of course, a bedload transport predictor. Most codes offer a choice of transport predictors; many are

available, and computational river hydraulics is cursed by the lack of any consensus as to which of them is most appropriate as a general predictor. Order-of-magnitude differences in predicted transport rates are not uncommon, see for example Vanoni (1975).

The suspended-load source term, as well as bed-sediment relations, become enormously more complicated when cohesive sediments are dealt with.

The interested reader is referred to Holly et al. (1990) or Fan (1988) for more background on the equations used and numerical methods employed for their solution. For the Missouri River application described in the next section, an implicit finite-difference technique is used for all but the advection-diffusion equation, which is solved by the method of characteristics.

Missouri River Example

As discussed by Sayre and Kennedy (1978), the Missouri River reach between Gavins Point Dam and Blair, Nebraska, has experienced severe degradation in the past 50 years. The bed level has lowered more than 2 m near Sioux City, Iowa, potentially compromising the structural integrity of bridge-pier foundations, reducing the efficiency of power-plant cooling-water intakes, and considerably changing the natural habitat through increased velocities, lowering of oxbow lake levels, and decrease in vegetative cover. This degradation seems to be the river's response to a series of interventions by man: (1) reduction of the sediment load entering the reach below Gavins Point Dam through closure of upstream dams, (2) regularization of annual flood hydrographs through storage and release cycles in upstream reservoirs, and (3) channelization of the river through spur-dike and artificial-cutoff construction, to form a reliable navigation channel and to reclaim flooded lands along the river.

Whatever the benefits accruing from these interventions, there also have been structural and environmental costs that may not have been foreseen when river engineering began in earnest in the early part of this century. Concerned with the possible future course of the river's continuing response to these interventions, the U.S. Army Corps of Engineers has been carefully monitoring the progress of the degradation and has conducted numerical modelling efforts to better understand it.

In 1981 the Omaha District of the U.S. Army Corps of Engineers commissioned the Iowa Institute of Hydraulic Research to construct a numerical mobile-bed model of the degrading reach of the Missouri River, with two objectives: identify the root cause of the degradation, if possible, and forecast the future course of the degradation.

The first-generation mobile-bed simulation code IALLUVIAL was developed for this study (Holly and Karim 1986). The CHARIMA code, whose equations are outlined above, is a third-generation descendant of IALLUVIAL (Holly et al. 1990). Results presented further on were obtained using the earlier IALLUVIAL code, but have been reproduced using CHARIMA.

The study reach is shown in Fig. 2. The computational model extends from Gavins Point Dam some 505 river kilometers (rkm) down to Rulo, Nebraska. Nine tributaries, including the Platte River, are represented as local water and sediment inflows. The upstream boundary condition of the model is water and sediment inflow through Gavins Point Dam; the downstream boundary condition is the stage-discharge rating curve at Rulo. The initial channel cross sections are those reported by the U.S. Army Corps of Engineers, representing the natural channel in 1960 from Gavins Point Dam to Ponca State Park, and the channelized sections (roughly rectangular, with a 180-m width) as of 1960 for the remainder of the model. The initial bed-sediment distributions are from U.S. Army Corps of Engineers measurements. It should be noted that the natural reach above Ponca State Park had already been subjected to at least 5 years of effect from the previous closure of Fort Randall and Gavins Point dams.

In an initial calibration and verification mode, the model was run for the 1960–80 period in a postdictive simulation. The simulation adopted repeated annual inflow hydrographs typical of the release schedules from Gavins Point Dam and of tributary springtime flooding. Figure 3 shows longitudinal profiles of bed level and water-surface elevation resulting from this simulation from Gavins Point Dam to Omaha, with the observed changes in water-surface elevation shown for comparison. The model captured the major features of the river's response, including the relative inactivity of its channel downstream of Omaha. The only calibration that was done, other than use of the Total Load Transport Model (TLTM) transport predictor that is known to be appropriate for this stretch of the Missouri River (Karim and

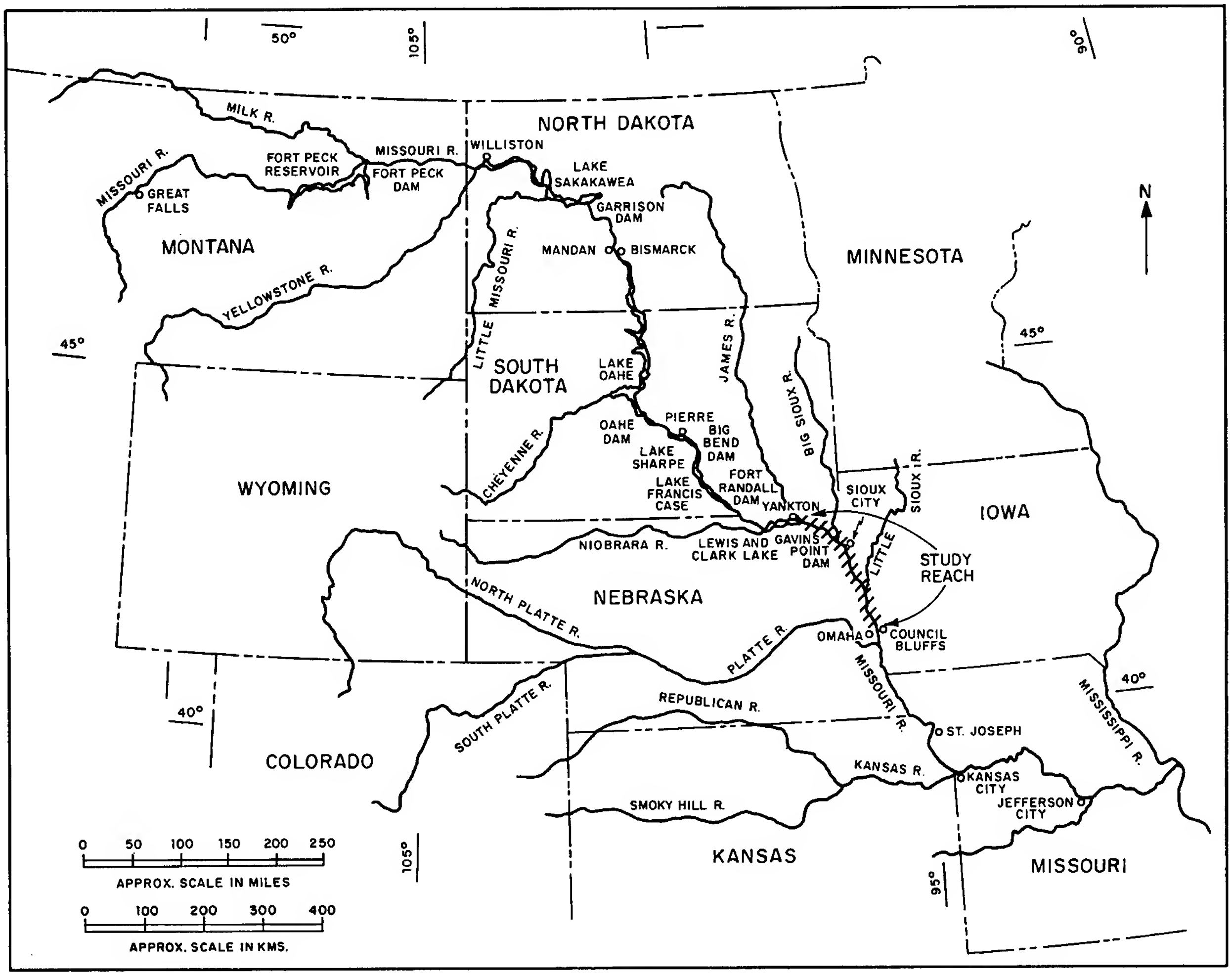

Fig. 2. Missouri River basin and study reach.

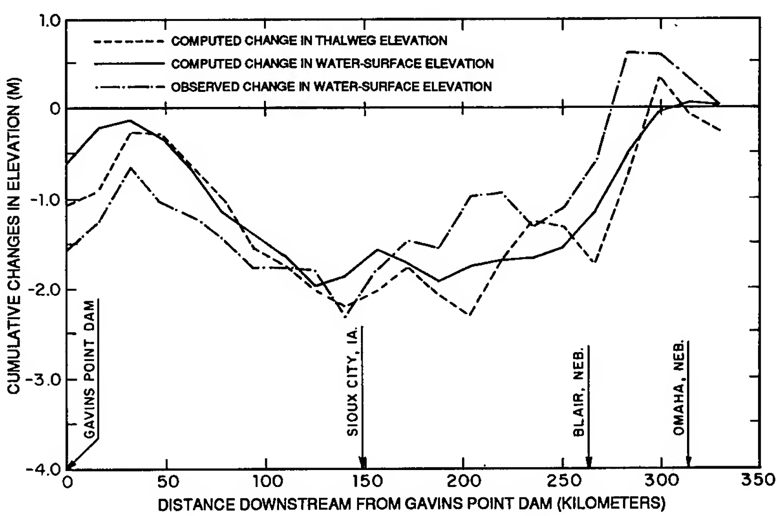

Fig. 3. 1960–80 simulation run.

Kennedy 1982), was adjustment of the initial bed-sediment diameters to account for the spatial heterogeneity not reflected in the sparse field measurements available.

Once the model had been verified, it was used to study a series of schematic scenarios in the interest of identifying the primary cause of the degradation and forecasting future degradation. These scenarios were as follows:

S1: Nominal 20-year simulation, a continuation of the 1960–80 verification run.

S2: Effect of out-of-basin diversion, simulated by reducing the Gavins Point Dam releases by an average of 116 cms (4,100 cfs) over the annual cycle.

S4: Effect of channelization, studied by widening the navigation channel from 183 to 244 m.

S5: Effect of channelization, studied by widening the navigation channel from 183 to 305 m.

S8: Effect of artificial armoring as a means of local degradation control, studied by increasing by about 10% the amount of bed sediment between 2.4 and 19.1 mm.

S9: Effect of modulation of Gavins Point Dam releases, studied by constant release of the mean annual discharge of 823 cms (29,000 cfs).

Figure 4 shows the computed time-evolution of bed level at Sioux City, Iowa, under these various scenarios. The initial rapid degradation for all runs is caused by the use of an initial armoring factor of zero, thereby failing to account for any residual protection of the bed surface by interlocking immobile particles in 1980. All the runs tend to reach a kind of equilibrium in 2–6 years. Then all but run S5 show the effects of the arrival of the degradation wave from upstream. The asymptotic approach to a new equilibrium is visible from about 15 years onward.

Runs S2 and S9 show that reduction and modulation of the mainstem water inflow can reduce the ultimate degradation by about 10 and 20 cm, respectively. Runs S4 and S8 show that a 61-m widening and artificial armoring could reduce the ultimate degradation by about 30 cm. Run S5 shows that a 122-m widening, which represents a return to nearly the pre-channelization natural-channel width, would virtually eliminate further degradation, though possibly at the expense of maintaining adequate navigation depths for part of the year. Analysis of similar results for these and other scenarios at all computational points of the model can be found in Holly and Karim (1983). Additional analyses of the effect of the Platte River sediment inflow in arresting degradation at and below Omaha can be found in Holly et al. (1986).

Although this Missouri River model has not been in active use in the past few years, it could be used to study other sediment-management scenarios of relevance to wildlife habitat. These could include: recovery of the temporal pattern of the natural (pre-dam) hydrograph, perhaps with some storage modulation; development of a sediment-bypass system for Gavins Point Dam; and artificial sediment supply to the tailwater of Gavins Point Dam.

Simulation Deficiencies

Although the Missouri River application has been presented somewhat optimistically, mobile-bed modelling is still in the dark ages insofar as reliable fidelity to physical processes is concerned, especially in 1-D applications. A few of the more prominent weaknesses and areas of concern are listed below.

Spatial Averaging

In their inability to resolve spatial heterogeneity of bed sediment and transport within a cross

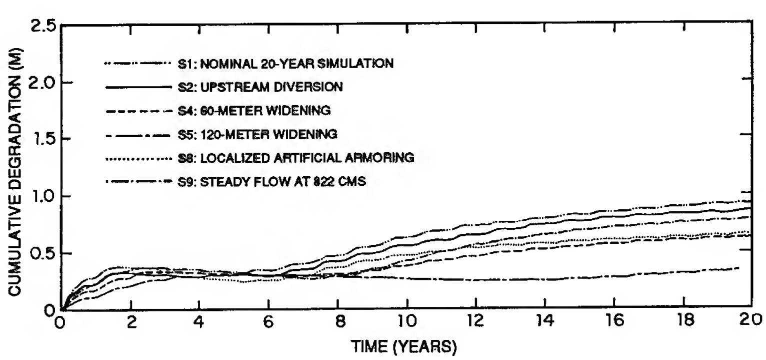

Fig. 4. Cumulative computed degradation at Sioux City, 1980–2000.

section, 1-D models must be considered only as models of idealized rivers having certain gross properties in common with the natural rivers they are supposed to emulate. Obviously, this weakness begins to disappear with 2- and 3-D models, although they too cannot resolve spatial heterogeneity at a scale finer than that of their computational grids.

Bedload and Suspended-load Source Predictors

Prediction of bedload transport capacity and the flux of sediment from the bed into the water column rely on a body of competing, inconsistent, empirical relations derived from laboratory and field experiments under supposed equilibrium conditions. The range of differences in various load predictors is well illustrated by Table 2.113 in Vanoni (1975). Mobile-bed models are not only subservient victims of the enormous uncertainties in the validity of such predictors for a particular situation, but also compound the potential error in assuming quasi-instantaneous satisfaction of equilibrium conditions (though this can be relaxed somewhat; see for example Holly and Rahuel 1989). Ultimately, one can only remove this uncertainty by incorporating a complete description of the dynamic forces acting on individual sediment particles. But this would require a complete description of the turbulent velocity fluctuations near the bed, and would have to account for the infinite variety of particle shapes, sizes, and interactions, an obviously impossible task. At present, and for the foreseeable future, the modeler's only recourse for the study of a particular river reach is to adopt the transport and source predictors that are known to be best adapted to that particular location, if possible, abandoning hope of adopting global predictors applicable to all cases.

Stochasticity

A basic premise of the modelling descriptions given here is that the processes involved are deterministic and rational; that is, that there is no randomness or uncertainty in the laws themselves. There is, however, a strong element of stochasticity in the water-sediment transport problem, and this has been explicitly recognized by some investigators, starting with the work of Gessler (1975). Sediment behavior at any particular moment at any particular location of a river probably should be considered as one realization of a random process.

Cohesion

Even if one can consider bedload and suspended-load predictors for noncohesive (loose) sediments as reasonably reliable within certain limits, all bets are off when electrochemical interaction of fine (clay) particles gives them a cohesive strength. Considerable work in this area has been done by Krone (1962) and his colleagues, but there is as yet no consensus as to the appropriate parameters, or indeed the very form of the entrainment laws, that should be used when cohesion occurs. Surface erosion of cohesive particles, notably their progressive detachment from the bed, is quite different from mass erosion, when an entire layer of cohesive material fails structurally and injects a large mass of bed material into the water column in a single event.

Bedforms

The assimilation of a river bed to a single surface of uniform properties, especially in 1-D models, necessarily ignores the complex interplay of bedforms and their intimate and strongly nonlinear relation with the flow hydrodynamics and sediment properties. Attempts are made in most models to take these interactions into account globally, for example through transport and flow-dependent bed roughness and relations between dune height and bed mixing layers, but a model of any dimension is destined to be unable to resolve the complex geometric features of bedforms and their interactions with the flow and sediment transport.

Armoring

Although sediment sorting (differential transport depending on particle size) can be represented in a rather straightforward manner insofar as bed-sediment accounting is concerned, accurate representation of bed-degradation protection through interlocking of a relatively small coverage of immobile particles is much more complex and challenging. This is especially true when part of a river bed may be armored while another is in active bed movement; such a distinction simply cannot be made with a 1-D model. Yet armoring can be the primary mechanism for arresting bed

degradation in nonequilibrium river response, as is the case for the Missouri River example discussed earlier.

Planform Geometry Adjustments

Whenever river banks are erodible, the river's response to perturbations can include both bed and bank adjustments. Most models, such as the ones described here, consider only bed response, implicitly assuming that the banks are stabilized or otherwise prevented from movement (this is often the case in developed rivers.) Although some of the modelling techniques outlined by Fan (1988) include explicit attempts to allocate river response between planform (bank-erosion, meandering) and bed (aggradation, degradation) changes, most do not. Yet this is clearly an important element of channel response to perturbations.

Simulation Opportunities

In addition to overall degradation and aggradation, mobile-bed models provide insight into perturbed-equilibrium effects on many habitat features of importance to the ecosystem, such as: water depths and velocities, water turbidity and solids content, water temperature (when thermal processes are included), ice-cover formation, actual bedload and suspended-load transport rates, and bed-surface sediment composition.

Using models that include planform adjustment (bank erosion and bar deposition) in their response, it is also possible to study the habitat effects of releasing stabilized banks in certain areas to achieve a natural widening, and to reconcile this response with navigation and flood-control needs.

The absolute predictions of bed-level change, turbidity increase, bed coarsening, and so forth must be viewed as suspect because of all the uncertainties described earlier. But the sensitivity of river response to uncertain factors, such as the sediment transport rate, grain-size distribution, bank erodibility, and so forth, can be studied with considerable confidence in such models. For example, in Fig. 4 one might be reluctant to bank on the Sioux City degradation in the year 2000 being within a few centimeters of the predicted value for run S1. But one might have considerably more confidence in saying that the degradation would be about 30 cm less if the channel were 60 m wider, and 60 cm less if it were 120 m wider.

A model also can provide valuable guidance for field sampling programs in indicating what parameters are of greatest significance for long-term response, and in indicating the particular river reaches in which relatively rapid or severe response justifies focused data-collection efforts.

For the river engineer charged with proposing a small number of alternative development scenarios to meet fixed objectives, a numerical model can be used to eliminate the obviously infeasible solutions, so that further field and physical-modelling efforts can be focused on those alternatives that seem to be the most viable ones.

But given the simulation deficiencies described above, does mobile-bed modelling have an important role to play in river-development planning and design? In our view, the answer is a strong but qualified yes. Numerical mobile-bed modelling must not be viewed as being a complete or definitive tool on which development should be based. It is, rather, to be included with field experience, field observations, analytic calculations, study of published experiences, and possibly physical modelling to support the engineer in what is ultimately his or her responsibility alone—to make the best possible design decisions with regard to present and future river and ecosystem responses. The river engineer must not abdicate decision responsibility to any one of these tools. The processes are so complex, and the time scale of river response is so long, that it is incumbent upon the river engineer to base decisions on all possible input.

The unique contribution of numerical mobile-bed modelling is that it enables the river engineer to acquire an intuitive feel for and understanding of the way a river system is apt to respond to changes over the long term. As an inexpensive and readily available tool, numerical modelling gives the engineer the opportunity to test a range of "what if" scenarios on the data set that emulates the real river.

Summary and Conclusions

It has been our purpose in this paper to temper enthusiasm for the predictive potential of mobile-bed numerical models with a sober realization of the fragile understanding of mobile-bed processes on which they are based. Issues of spatial heterogeneity, stochastic properties of turbulence, cohesive

sediment bonds, bedform processes, bed armoring, and so forth combine to force recognition that mobile-bed models, especially 1-D ones, must be thought of more as vehicles for gaining insight and gauging sensitivity than as absolute predictors. The Missouri River example points out the kind of insight and understanding that can be gained from such models, even if the absolute predictions must be treated with considerable caution.

If a numerical mobile-bed modelling effort fails to live up to nominal expectations, it still represents a productive expenditure of time and effort. The modelling effort itself, whether it involves just data assembly for an existing code or development of a code itself, forces the modeler into an intimate relationship with the river's topography, hydrology, sedimentology, and habitat, and their interactions. Out of this relationship and resultant insight grows the kind of balanced understanding of the river and its ecosystem, and of their response to perturbations, which leads to informed river-development decisions reflecting the needs not only of man, but also of other life dependent on the riverine habitat.

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Divergent Response of Riparian Vegetation to Flow Regulation on the Missouri and Platte Rivers

by

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Abstract. The arboreal vegetation along the Platte and Missouri rivers has responded very differently to water development. *Populus–Salix* woodland has expanded rapidly into Platte River channels, while it has failed to regenerate along the Missouri River in North Dakota. The divergent response is the result of different geomorphology and water use patterns. The Platte is a braided stream with a large proportion of its flow diverted for cropland irrigation. The Missouri is a meandering stream with low irrigation usage. Management designed to maintain biological diversity and ecosystem function must acknowledge the differences and must be tailored to each river system.

Riparian vegetation is valued for its benefits to wildlife, fisheries, recreation, and watershed protection (Johnson and McCormick 1979; Ohmart et al. 1988). Biodiversity and productivity of stream systems in particular are strongly influenced by the composition and structure of streamside vegetation (Cummins 1974). For example, riparian vegetation provides much of the raw organic material for detritus-based stream systems, shades the stream thereby reducing thermal stress on organisms, controls streambank erosion and sedimentation patterns, and contributes coarse woody debris for instream fish habitat.

Riparian vegetation occurs in a zone of intense interaction between aquatic and terrestrial ecosystems. The highly dynamic disturbance regime associated with this zone causes high plant mortality but also frequent opportunity for plant colonization. Thus, long-term maintenance of riparian ecosystems often requires frequent disturbance caused by a highly variable flow regime, ranging from severe floods to droughts (Fenner et al. 1985; Stromberg et al. 1991).

Flow regulation has modified riparian zones and reduced benefits to adjacent ecosystems. For example, flow alterations by humans have contributed to the establishment of exotic trees (e.g., *Tamarix, Elaeagnus*) along western U.S. rivers, which have lower value than native trees (*Populus, Salix*) for wildlife (Knopf et al. 1988; Ohmart et al. 1988). Simultaneously, altered flow regime, particularly reduced peak flow, has reduced recruitment of native riparian trees in the Southwest (Stromberg and Patten 1990). Similar regeneration problems with *Populus* and *Salix* have occurred in the northern Great Plains because of altered flow caused by large dams. Bradley and Smith (1986) concluded that a post-dam decline in *Populus* and *Salix* recruitment along the Milk River in Montana and Alberta was caused by reduced frequency of peak flows greater than the 2-year-return annual flood during the seed dispersal period. Lower peaks failed to produce point bars at high enough elevations to enable new germinants to withstand later peak flows. Johnson et al. (1976) and Reily and Johnson (1982) detected changes in several ecological processes in the riparian zone of the Missouri River after dam construction, including slower growth of most tree species and low seedling recruitment

of *Populus* and *Salix*. The long-term effect would be a loss of the now extensive and mature *Populus–Salix* forests and a decrease in biodiversity within the riparian zone.

Water development produced the opposite effect on riparian vegetation in the Platte River in the central Great Plains. Reduced flows caused major expansion of *Populus–Salix* woodlands by increasing tree seedling recruitment and survival in the riverbed (Johnson 1993). The river was transformed from one with wide channels and scattered woodland in presettlement times to one with much narrower, tree-lined channels and extensive woodland occupying the floodplain.

The contrasting trend of increasing pioneer woodland in the Platte River with decreasing pioneer woodland along the Missouri River is striking for two developed rivers in the Great Plains, both of which originate in the Rocky Mountains and have similar climate and vegetation. The purpose of this paper is to review patterns of change for each river, examine the causes of the divergence, and identify management options for long-term maintenance of riparian ecosystem values associated with these large river systems. The present comparison is based largely on published results of riparian research conducted during the past two decades (Johnson et al. 1976; Reily and Johnson 1982; Johnson 1992, 1993).

Missouri River

At present about one-third of the mainstem Missouri River is free-flowing, one-third consists of massive impoundments, and one-third is a continuous open navigation channel (Hesse et al. 1988). Impoundments are concentrated on the upper Missouri River; six large mainstem reservoirs occur in the Dakotas and Montana. Oahe Reservoir (South Dakota) alone eliminated over 123,000 ha of riparian and floodplain lands in the Dakotas (Hesse et al. 1988). Remnants of the floodplain forest, however, exist in gaps between the reservoirs.

Johnson et al. (1976) and Reily and Johnson (1982) noted that major changes in riparian vegetation were imminent along the upper Missouri River because of reservoir construction and operation. These determinations were based on investigations of a 100-km remnant floodplain gap between Garrison Dam (Lake Sakakawea) in North Dakota and Oahe Reservoir (Oahe Dam) in South Dakota. Their research detected several changes following dam construction, including a decline in the radial growth of most tree species, low seedling recruitment of *Populus* and *Salix*, and low survival of *Acer negundo* L. and *Ulmus americana* L. seedlings and saplings.

Populus–Salix forests historically have dominated the Missouri River floodplain because of the highly dynamic nature of the river channel. Before the large dams, the river meandered rapidly across the floodplain during floods. This process deposited alluvium on the inside of river curves (point bars), while on the opposite side it eroded established banks often covered with forest vegetation. Point bars were optimal habitat for *Populus* and *Salix* establishment (Moss 1938; Noble 1979). Seed dispersal generally coincided with receding spring water levels and the exposure of newly-formed point bars (Fenner et al. 1985; Johnson 1992).

Pioneer *Populus–Salix* forests that escaped erosion by the meandering river were replaced by later successional species including *Fraxinus*, *Ulmus*, and *Acer*, which reproduced in the *Populus–Salix* forest understory. *Populus* and *Salix* are classic pioneer species unable to reproduce successfully in forest conditions; hence, channel meandering was necessary to perpetuate these extensive forests on the floodplain.

Dams greatly reduced peak flows but not total annual flow (Johnson 1992). Between 1928 and 1953, about two-thirds of the annual peak flows at Bismarck, North Dakota, exceeded 2,500 m^3/s; since 1953, no peak has exceeded 2,500. The highest peak of record before the closure of Garrison Dam was 14,150 m^3/s; the highest peak flow since dam closure was 1,950 m^3/s in 1975.

Reduced peak flows caused reductions in river meandering rates. Bank erosion rates fell from the pre-dam average of 93 ha/year to 21 ha/year during the post-dam period (Johnson 1992). Bank accretion rates fell from 111 ha/year to 1.3 ha/year. Thus, post-dam erosion rates were only about 25% of pre-dam rates, and accretion rates were only 1% of pre-dam rates. The product of these changes has been a locationally stable river channel with little generation of stable point bars for colonization by pioneer tree species and little erosion of established forests and fields.

A mathematical model that integrates river meandering rate and forest succession (Johnson 1992) simulated an abrupt decline in the area of *Populus–Salix* forests in the future. Land survey

data showed that pioneer forests dominated the floodplain before settlement; temporal variation in the area of pioneer forests was caused by major flood events (Fig. 1). Following the construction of Garrison Dam, pioneer forest was shown to decline to less than half of its presettlement area after 150 years. The proportion of pioneer forest at steady state (not shown) was only several percent of the floodplain area. Equilibrium forest (successionally advanced forest without *Populus* or *Salix*) was a minor component of the vegetation in the presettlement period but dominated the floodplain in the post-dam scenario after 100 years.

The sharp decline in the area of pioneer forest is expected to occur because of the slow rate of point bar formation and the natural conversion of existing pioneer forest to forests of later successional species. The simulation indicates that the pre-dam dominance of the floodplain forest vegetation by *Populus* and *Salix* cannot be maintained under the current extremely low meandering rate. A new post-dam steady state dominated by equilibrium forests would be reached about 200 years after the closure of Garrison Dam. *Populus–Salix* forests will occur as a narrow gallery forest rather than as extensive bottoms, as they now occur.

Platte River

The Platte River and its major tributaries have had a long and complex history of water development (Eschner et al. 1983; Hadley et al. 1987; Knopf and Scott 1990). Briefly, the earliest water development for agriculture in the Platte River system occurred along the South Platte and North Platte rivers in the mid-1800's. Dams were built on both rivers in the early to mid-1900's. Flow has been augmented substantially by transbasin diversions of surface water. No mainstem reservoirs were constructed on the Platte River except for small impoundments behind diversion dams. Water diverted at the confluence of the North Platte and South Platte rivers formed a series of off-channel reservoirs used for recreation, irrigation, and hydropower generation. No mainstem dams have been built on the Platte or North Platte rivers since 1956. Up to 70% of the flow of the North Platte and South Platte rivers is diverted for cropland irrigation, although as much as half of that diverted returns to the rivers via subsurface flow.

Populus–Salix woodland expanded into formerly active channels of the Platte River coincident with the construction of dams and water diversions (Johnson 1993). The rate of expansion of woodland (or loss of active channel area) has been dramatic and geographically variable. For example, woodland area in the Platte River west of Kearney increased from about 15% of the floodplain area in 1938 to 70% in 1986 (Fig. 2). Gothenburg showed more modest gains but began the series with a much larger woodland proportion, which probably developed before 1938 before aerial photographs were available (Fig. 2). Woodland area has stabilized in most Platte River reaches in the last 10–20 years.

Statistical models indicated that the rate of channel replacement by woodland was strongly affected by river flow during June (Johnson 1993).

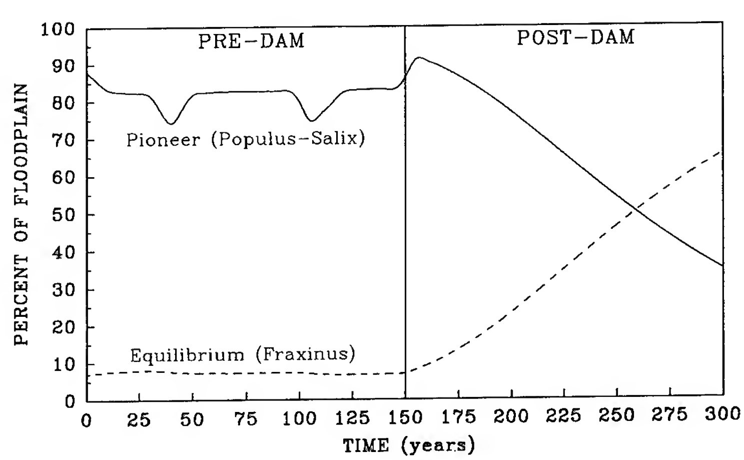

Fig. 1. Steady state forest composition on the Missouri River floodplain during the presettlement (pre-dam) and after closure of Garrison Dam based on a simulation model (Johnson 1992). Erosion and deposition (accretion) rates were changed in the model at time = 150 years.

June flow controlled seedling recruitment of *Populus* and *Salix* because it coincided with the primary seed dispersal period. Historic reductions in June flow to provide irrigation for crops and to fill reservoirs exposed sandbars, allowing tree recruitment to occur. The rate of woodland expansion increased during periods of climatic drought. Seedling survival also was higher during the post-development period because of reduced ice action and sandbar erosion.

The proportion of active channel to woodland area has stabilized in recent decades because little significant water development has occurred since the mid-1950's. Thus, woodland and channel have come into equilibrium because flows have covered a larger proportion of the channel as channel area has declined. This has restricted recruitment to a smaller and smaller area of the active channel. Reduced rates of woodland expansion have led to relatively stable open channel area and habitat values for migratory birds.

The greatly expanded *Populus–Salix* woodland may itself decline in the future because of the lack of new recruitment sites and the inability of the river to rework formerly active portions of the channel now occupied by woodland. Thus, the potential exists for successional replacement and reduced faunal diversity primarily because other later successional tree species provide less habitat for cavity-nesting birds and certain mammals than pioneer *Populus–Salix* forest.

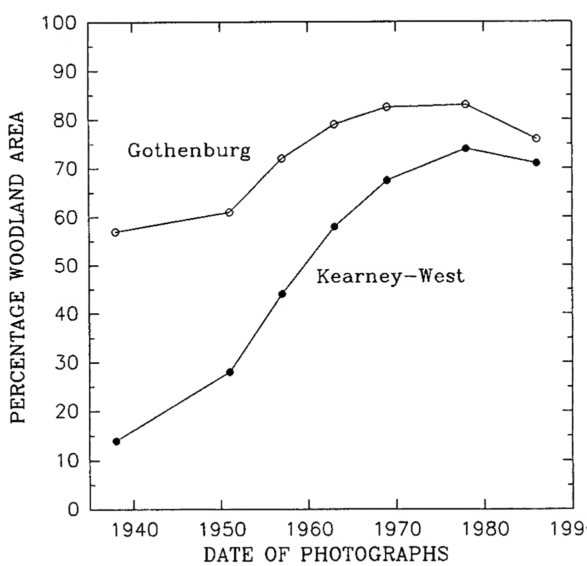

Fig. 2. Changes in woodland area in the Platte River near Gothenburg and Kearney, Nebraska. Area estimates were made from aerial photographs taken between 1938 and 1986.

Causes of Divergent Response

Divergent responses of river systems to water resource development have numerous possible causes, including geomorphic type, presence of exotic species, type and magnitude of water resource development, grazing intensity, agricultural activity, and others. Among these, geomorphic type seems to be a major factor, illustrated by the opposite responses to damming by the meandering Missouri River and braided Platte River.

The two rivers differ markedly in geomorphic and hydrologic characteristics (Table). Braided streams are relatively wide and shallow, and large reductions in flow cause large reductions in the width of the wetted channel and small decreases in average depth. The proportion of the active channel exposed and available for plant colonization is highly sensitive to small flow changes in the low flow range.

Meandering rivers inside their normal banks, however, are considerably deeper and narrower than braided rivers (Table). Except at flood stage, large changes in flow translate into large changes in depth and small changes in wetted width. Most permanent vegetation is located on the floodplain outside the channel because the large vertical rise in river stage during floods allows little successful in-channel plant establishment.

High flow events are extremely important in both systems but affect vegetation differently. In the Platte, high flows reduce recruitment and maintain wide channels, whereas in the Missouri, high flows create the geomorphic environment required for the establishment of riparian vegetation.

The divergent response of these two rivers also has been affected by differences in water development. Although large reservoirs occur on both river systems, their uses differ. The Missouri River reservoirs are operated to control floods, provide hydroelectric power, and support recreation. Little water is used for cropland irrigation in the Dakotas. In contrast, a large portion of the flow of the Platte River is diverted for cropland irrigation. As stated above, the geomorphic nature of braided rivers such as the Platte makes them extremely sensitive to flow reductions. Had only peak flows been reduced in the Platte River and

Table. Geomorphic differences between the Missouri and Platte rivers.

Characteristic	Missouri River	Platte River
Sediment size	clay to sand	sand to gravel
Vertical range	approx. 2 m	approx. 10–12 m
Total active channel width	narrow	wide
Stream gradient[a]	gentle (0.00016 m/m)	steep (0.00125 m/m)
Average depth	less than 1 m	approx. 12 m

[a] Kircher 1983; Osterkamp and Hedman 1982.

not total annual flow, as was the situation for the Missouri River, woodland expansion would have occurred at greatly reduced rates.

Management

The divergent responses of these two systems suggest different corrective measures. The primary options that could lead to increased regeneration of *Populus–Salix* forest along the Missouri River in gaps between the reservoirs are tree planting and prescribed peak flows. Pioneer trees could be planted on agricultural land on the floodplain or after clearing of older or degraded forests. While planting may maintain certain values, such as habitat for cavity-nesting birds, planted forests will differ from those initiated through river meandering and sandbar succession. Naturally regenerated pioneer forests contained a large percentage of facultative wetland plant species because they developed on relatively low sandbars and were repeatedly aggraded by siltation from periodic floods (Keammerer et al. 1975). In contrast, most sites available for planting are on relatively high terraces and would probably be impoverished in native wetland plant diversity compared with their naturally regenerated counterparts.

A second option would be to release water from Garrison Dam to induce channel movement and point bar formation. Prescribed flows must be large enough to erode banks on the outside of river curves and to produce point bars though sedimentation on the inside of river curves. The point bars created must be high enough to enable tree recruitment to survive subsequent minor floods. Implementation of this option, however, is limited by the increased chances of damage to persons and property by floods. Since the floodplain has been protected from flooding by dams, the human population has moved onto the floodplain, particularly in Bismarck. Numerous legal, scientific, and political issues would have to be resolved before effective flooding could be reintroduced into the Missouri River ecosystem. Neither management option represents the perfect solution, yet if the preservation of biological diversity and ecosystem function is a goal, some action must be taken.

Platte River channels have stabilized in width in recent decades, but further management may be necessary to eliminate short-term narrowing during natural drought periods. More permanent narrowing could occur if climate changed or if exploitation of flow for irrigation increased. Further woodland expansion and channel narrowing may adversely affect migratory birds that use wide, active channels (U.S. Fish and Wildlife Service 1981).

Several management options could assist in preventing further woodland expansion into active channels (Johnson 1993). Tree seeds could be prohibited from germinating in the active channel by augmenting June flows to cover all unvegetated sandbars. Or the mortality of young tree seedlings could be increased by raising winter flows to increase ice scouring of the riverbed, increasing spring peak erosive flows to remove seedlings, or reducing late summer flows to increase desiccation. Other researchers (Currier and Stubbendieck 1985) have recommended clearing woodland from banks and islands to maintain wide channels.

These options vary in water use, the chances of incurring property damage, reliability, cost, and probably effectiveness. The best approach may be to combine options, based on measurements of relative success from a permanent plot network that monitors seedling recruitment and survival. Seedling monitoring could determine, first, whether flow management was needed and, second, which option was most effective. Considerable experimentation would be needed to identify the degree to which flows can be controlled and timed to coincide with critical events such as ice formation and break-up and seedling life history stages (e.g., seed dispersal, germination).

The divergent response of the riparian ecosystem in these two systems indicates the need to develop a classification of rivers according to their sensitivity to flow regulation. This would assist in the accurate prediction of the effect of future water development on relatively natural rivers of

a range of types and could be used to tailor corrective management plans for developed rivers in need of restoration. With the large increase in riparian research in the western United States in the past decade, data are now available to start such a synthesis.

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Rehabilitating the Aquatic Ecosystem of Rainy Lake and Namakan Reservoir by Restoration of a More Natural Hydrologic Regime

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Abstract. The 38,600-km^2 Rainy Lake watershed, part of the Hudson Bay drainage, contains a complex network of lakes, ponds, and connecting rivers and streams. Hydrologic conditions in Rainy Lake–Namakan Reservoir have been regulated by dams since the early 1900's. Regulation has altered the magnitude and timing of water level fluctuations and has removed much of the hydrologic variability the lakes would experience under natural conditions. The controlled water levels adversely affect key elements of the aquatic ecosystem: littoral vegetation, benthic organisms, fish, aquatic birds, and furbearers. Specific water levels, particularly spawning season levels, and annual fluctuations of water levels influence fish densities and spawning success. Simulation models indicate that phytoplankton biomass and primary production may also be affected by the regulatory program. As part of a Federal Energy Regulatory Commission licensing action, and based on recent research, alternative water level regulations were developed by various user groups. Regulations that emulate natural fluctuations in water levels, including annual and long-term variability, may overcome the adverse biological effects of the present program. Whereas conflicting needs of water users may prevent implementation of such alternatives and may preclude complete restoration of the Rainy Lake-Namakan Reservoir system, a regulatory program that is more ecologically sound seems possible, given our understanding of relations between the hydrologic regime and the various biological components. That knowledge, and information on other users' needs, has been used by a committee representing private

and public interests to develop a compromise regulatory program that provides for human and biological needs.

The aquatic ecosystem of the Rainy Lake basin has a long history of use by humans. Native Americans were sustained by its resources for thousands of years (Martin et al. 1947). Europeans, who first entered the region in the 1660's, traded with the Indians for furs, fish, and wild rice which were harvested from area waters (Nute 1941; Holzkamm et al. 1988). In the past 100 years, human influences on the aquatic ecosystem increased substantially. The principal effects were associated with commercial and recreational fishing, the introduction of nonnative fish species, and manipulation of water levels by the construction of dams at the outlets of Rainy and Namakan lakes.

In this paper, we focus on the effect of water level regulation because it can affect all components of the ecosystem. Water level regulation can change energy flow through the system and can alter biological communities (Benson 1973; Baxter 1977; Kimmel and Groeger 1986; Prosser 1986). Our objectives are to summarize the results of studies conducted to determine effects of water regulation on selected species and communities, present a method for developing and evaluating alternative regulatory procedures for reducing those effects, and describe how the method is being used by a group representing private and public interests to select a more environmentally favorable regulatory program.

Study Area

The 38,600-km^2 Rainy Lake basin forms part of the headwaters of the Hudson Bay watershed. About 70% of the basin is in Ontario, and the remainder is in Minnesota (Fig. 1). In general, the

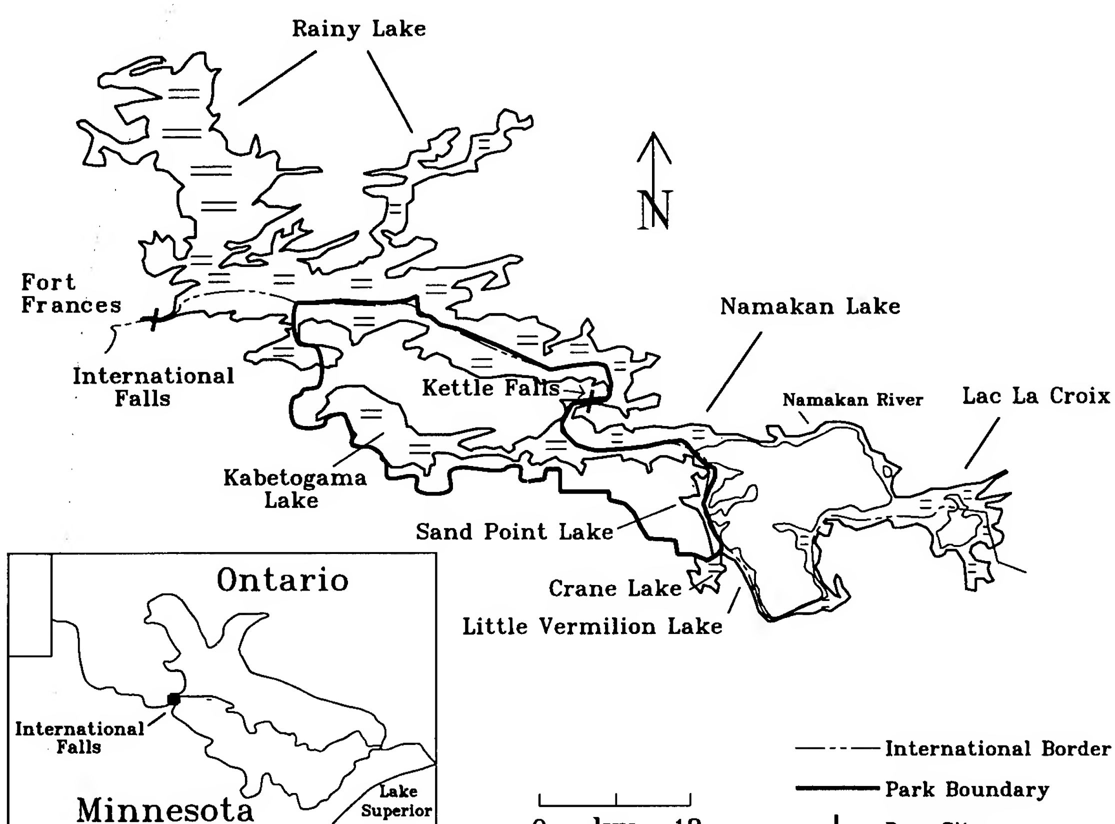

Fig. 1. Map of the Rainy Lake watershed (*inset*), Voyageurs National Park, and the lakes and reservoir discussed in this paper.

watershed is forested and characterized by thin soils, frequent outcrops of Precambrian rocks, and numerous lakes, ponds, and interconnecting rivers and streams. Parks and wilderness areas compose 25% of the basin; the major units are the Quetico Provincial Park in Ontario and the Boundary Waters Canoe Area and Voyageurs National Park in Minnesota.

Flow through the basin is generally northwesterly along the International Boundary. Changes in flow initiated at the headwaters take about 21 days, under average flow conditions, to reach the outlet of Rainy Lake. In traveling the 338 km between these two points, the waters drop about 135 m. Average flow at the outlet of Rainy Lake from 1905 to 1979 was 277 m^3/s; extremes ranged from 1 to 1,360 m^3/s. The highest flows in the major rivers typically occur during the spring freshet, which extends from April through June.

Rainy Lake, the largest lake in the basin, has a surface area of 858 km^2, 75% of which is in Ontario. The lake has a rocky, irregular shoreline and three distinct basins: the North Arm, Redgut Bay, and the South Arm. Namakan Reservoir lies immediately upstream of Rainy Lake and encompasses Namakan, Kabetogama, Sand Point, Crane, and Little Vermilion lakes. The reservoir has a surface area of 260 km^2, 77% of which is in Minnesota.

The area has a continental climate, characterized by moderately warm summers and long, cold winters (National Oceanic and Atmospheric Administration 1991). The frost-free season ranges from 110 to 130 days. Lakes are typically ice covered 5–6 months of the year. Average annual precipitation is about 68 cm, 30% of which comes in the form of snow. Precipitation is usually heaviest from June through August. Annual evaporation from all surfaces in the basin averages 49 cm, evaporation from lake surfaces averages 63 cm.

Water Level Regulation

The water level in Rainy Lake has been controlled since 1909 by a hydroelectric dam on its outlet, the Rainy River at International Falls, Minnesota and Fort Frances, Ontario (Fig. 1). Two dams at the outlets of Namakan Lake have controlled the water levels of Namakan Reservoir since 1914 (Fig. 1). Because Rainy Lake and Namakan Reservoir are border waters shared by the two countries, the dams and lakes are regulated by the International Joint Commission. The dams and lake levels are managed for the authorized purposes of power production, navigation, domestic water supply, sanitation, recreation, and other public purposes. Although regulated by the International Joint Commission, the dams have always been owned and operated by private industry. Their day-to-day operation is usually left to the industry, the International Joint Commission becoming involved only if its rules are not, or cannot be, followed.

The International Joint Commission's water management programs, which are commonly referred to as "rule curves," use larger than natural fluctuations in lake levels on Namakan Reservoir to maintain less than natural fluctuations on Rainy Lake. The rule curves require that water levels be within a defined band of lake elevations at any time of the year (Fig. 2). Additionally, the program for Rainy Lake requires minimum discharges for pollution abatement to the Rainy River of 113 m^3/s between sunrise and sunset in the months of May to October and 93.4 m^3/s at all other times.

Under the current rule curves, which have been in effect since 1970, annual water level fluctuations have averaged 2.7 m on Namakan Reservoir and 1.1 m on Rainy Lake. Namakan Reservoir's fluctuation is about 0.9 m greater than the estimated natural or predam fluctuation, whereas Rainy Lake's is 0.8 m less (Fig. 2; Flug 1986). Namakan Reservoir's overwinter (October to April) drawdown under the 1970 rule curve has averaged 2.3 m, which is 2.0 m greater than the estimated natural fluctuation for this period. Rainy Lake's overwinter drawdown has averaged 0.8 m, which is similar to the 0.7 m estimated natural fluctuation. The timing of the fluctuations has also been altered under the regulated system, particularly on Namakan Reservoir. Regulated lake levels usually peak in late June or early July rather than late May or early June, as they did before dam construction, and they remain stable throughout the summer rather than gradually declining. Thus, the International Joint Commission's rule curves have altered both the annual magnitude and timing of lake level fluctuations, and dampened the amplitude of yearly fluctuations in water levels (Figs. 2 and 3).

Environmental Concerns

Concern about the effects of water level regulation on the aquatic biota has existed since the

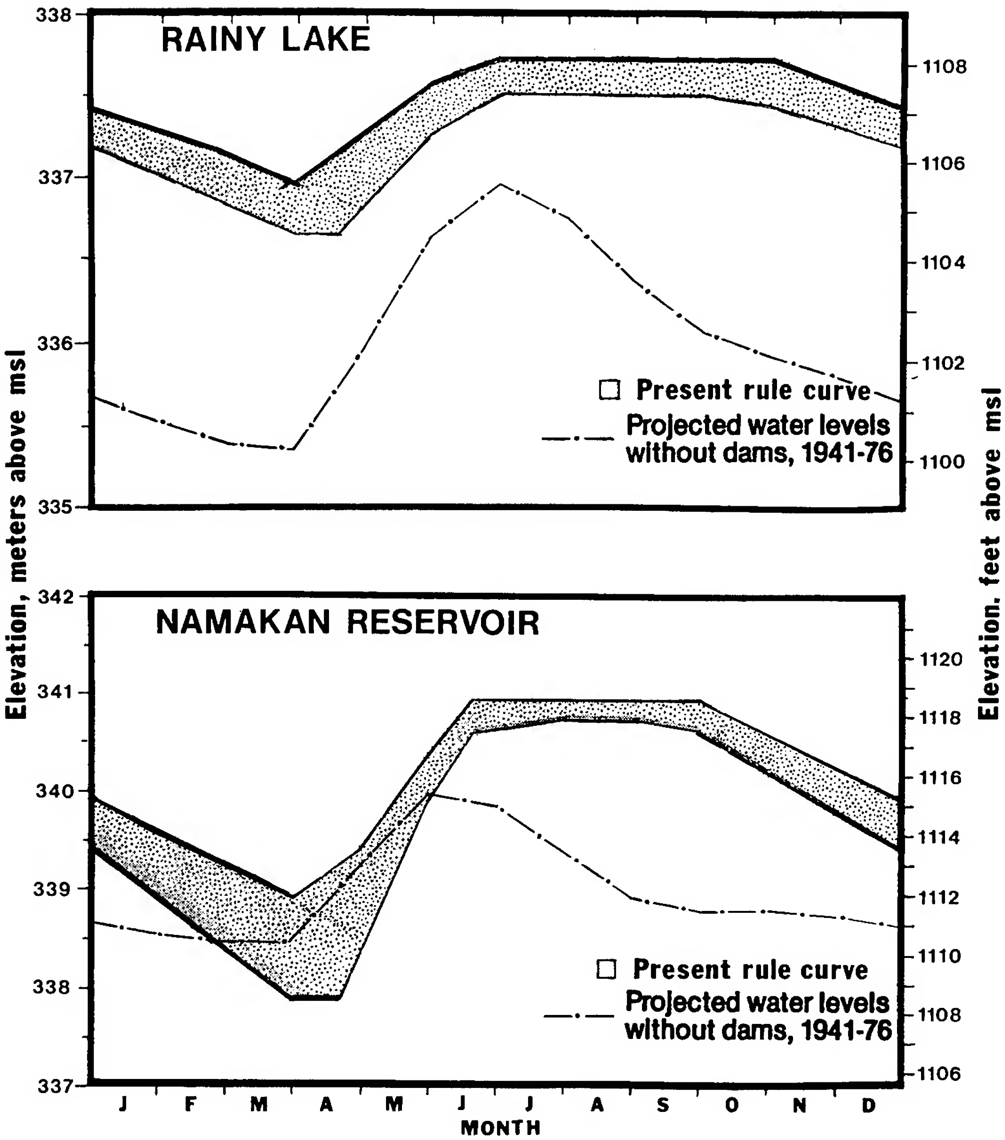

Fig. 2. Present water management programs (*rule curves*) and computed natural lake levels for Rainy Lake and Namakan Reservoir, Minnesota and Ontario. Elevations are given in meters and feet above mean sea level.

dams were constructed. The International Joint Commission's final report on the Rainy Lake Reference (1934) included statements from numerous parties expressing concerns about the possible effect of raising and regulating lake levels. The primary concern has been for the relation between lake levels and the fish community (Sharp 1941; Johnson et al. 1966; Chevalier 1977; Osborn et al. 1981).

The establishment of Voyageurs National Park in 1975, with its emphasis on restoring and preserving the natural environment, heightened concerns about effects of regulated lake levels on the aquatic ecosystem of Rainy Lake and Namakan Reservoir (Cole 1979, 1982). The effect of the fluctuating water levels on the littoral zone biota was a particular concern.

Further evidence of concern was the requirement in the Federal Energy Regulatory Commission's 1987 license for the International Falls dam that the dam owner "develop a water-level management plan for Rainy Lake to ensure the protection and enhancement of water quality, fish and wildlife, and recreational resources." This plan was to be based on studies conducted by Voyageurs National Park and any other studies conducted by the licensee after consultation with the U.S. Fish and Wildlife Service, the National Park

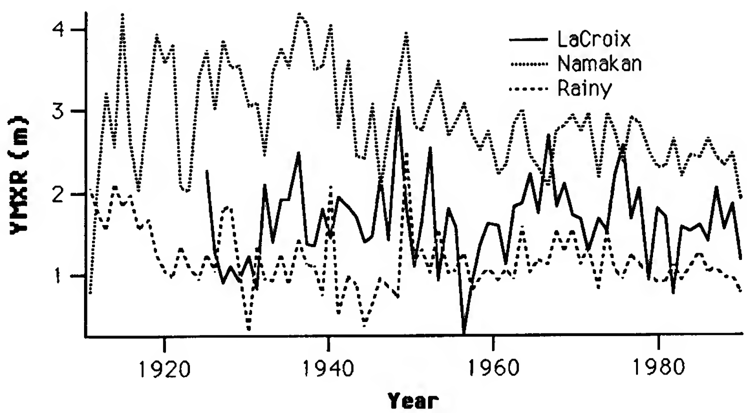

Fig. 3. Annual water level fluctuations (YMXR = maximum-minimum) in Rainy Lake, Namakan Reservoir, and Lac La Croix, 1911–90.

Service, and the Minnesota Department of Natural Resources.

Methods

General Approach

In the 1980's, the National Park Service, in response to these continued concerns, initiated a research program to (1) assess effects of regulated lake levels on the aquatic ecosystem of Rainy Lake and Namakan Reservoir, and (2) develop alternatives to the water management program (Kallemeyn 1983). The first component of the research program examined effects of the water management program (1970 rule curves) on selected species and communities thought to be sensitive to changes in water levels. The second component developed a hydrological model that could be used to assess alternative regulatory programs (Flug 1986). This model simulated the multi-lake system beginning with inflows to Namakan Reservoir and ending with outflows from Lake of the Woods, a large lake (3,850 km^2) located about 130 km downstream from Rainy Lake. To restrict the modeling effects to this area, outflows from Lake of the Woods were given priority and were forced to match actual historic releases. The model also provided for all legally mandated discharges for pollution abatement.

This program design was used because it would allow development and presentation of meaningful recommendations for alternative regulatory programs if research showed the water management program was adversely affecting the aquatic biota. It also allowed testing whether more natural water management scenarios could be used to reduce adverse effects on the biota without seriously conflicting with other authorized water uses (Cole 1982). Lastly, this information could serve as baseline data that could be used to evaluate the effects of any new water regulatory program that might be implemented.

Sampling Methods

Following are brief descriptions of the sampling methods used in the various National Park Service-supported studies and in another study sponsored by the Minnesota Department of Natural Resources, the Ontario Ministry of Natural Resources, and the dam owner in response to the Federal Energy Regulatory Commission license (Cohen and Radomski 1993). In 1992, the dam owner also sponsored the development of another hydrological model called SIMUL8, which mathematically simulates the operation of Rainy Lake and Namakan Reservoir (Acres International Limited 1993). Refer to the cited papers and reports for complete descriptions of the methods used.

Water quality in Rainy, Kabetogama, Namakan, and Sand Point lakes was monitored from 1977 to 1984 by Payne (1991) and in 1985 and 1986 by Kepner and Stottlemyer (1988). Payne's (1991) analysis was based on composite water samples, taken in May and August from the top, center, and bottom of a water column equal to twice the Secchi disk reading, that were analyzed using the methods described by Brown et al. (1970), Goerlitz and Brown (1972), and Skougstad et al. (1979). Kepner and Stottlemyer (1988) sampled monthly during the ice-free season. They measured primary production with the in situ ^{14}C method (Steemann-Nielsen 1952; Lind 1979; Wetzel and Likens 1979) and chlorophyll *a* spectrophotometrically, as

outlined by the American Public Health Association (1980) and modified for dimethyl sulfoxide extraction per Burnison (1980).

Wilcox and Meeker (1991) compared aquatic macrophyte communities in Rainy and Namakan lakes with those in Lac La Croix, an unregulated lake located 32 km upstream from Namakan Lake (Fig. 1), to determine the effects of the altered hydrologic regimes. Lac La Croix's mean annual fluctuation of 1.6 m falls between those of Rainy (1.1 m) and Namakan (2.7 m) lakes. Also, its water level typically declines after early June, rather than remaining stable, and exhibits greater year-to-year variability (Fig. 3). In each lake, aquatic macrophytes were sampled along four depth contours selected to represent specific habitat types in the unregulated lake. Species identifications and percent cover estimations were made in twenty 1-m^2 quadrats on each transect. Importance values were calculated for each taxon as the sum of relative frequency and relative mean cover on each transect. The vegetation data were analyzed using standard summary statistics, Sorenson's index (Mueller-Dombois and Ellenburg 1974), and detrended correspondence analysis (McCune 1987).

Kraft (1988) compared benthic communities in Kabetogama, Namakan, and Sand Point lakes with those in Rainy Lake to assess the effect of the greater than natural overwinter drawdown on littoral zone macroinvertebrates in Namakan Reservoir. Invertebrates were collected with an Ekman grab with samples taken on transects at depths of 1, 2, 3, 4, and 5 m. Sampling was confined to summer except on Kabetogama Lake where samples were also collected throughout fall and winter. Invertebrates were identified to genus or higher taxonomic level and counted. A Shannon-Wiener diversity index and an equitability value (Krebs 1972) were determined for each sample. The Wilcoxon signed rank test or the Mann-Whitney U statistic was used to test for differences between lakes in number of invertebrates, taxa, selected taxa, and diversity.

Effects of regulated lake levels on common loon (*Gavia immer*) and other shore and marsh nesting birds were studied in Rainy Lake and Namakan Reservoir from 1983 to 1986 (Reiser 1988). Intensive shoreline searches were used to determine adult bird densities and to locate nests. Nests and resulting broods were monitored to determine hatching and fledging rates. Nesting habitat, climatological, hydrological, and lake characteristic data were collected for use in evaluating their effects on nesting and reproductive success.

Effects of regulated lake levels on the aquatic furbearers—beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and river otter (*Lutra canadensis*)—were evaluated by comparing densities, behavior, and standard morphological measurements of animals from Rainy Lake and Namakan Reservoir (Route and Peterson 1988; Smith and Peterson 1988, 1991; Thurber et al. 1991). Lodge counts provided indices of abundance for beaver, while animals that were livetrapped and radio-implanted were used to study behavior, movements, and mortality. Estimates of muskrat densities were obtained from house counts, live-trap catches, and recaptures of marked animals. Radio-implants, sign surveys, and visual counts of marked and unmarked animals were used in the river otter study.

Kallemeyn (1987a, 1987b) evaluated the relation between spawning season water levels and reproductive success of walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), and northern pike (*Esox lucius*) by comparing seine and trapnet catches of age-0 fish with spawning season water levels. The quantity and availability of northern pike spawning habitat was determined from topographic maps and vegetation cover surveys. Cohen and Radomski (1993) examined relations among the fish populations, the fishery, and water level regulation in Rainy Lake and Namakan Reservoir from the context of ecosystem processes. For an index of ecosystem processes, they used the annual fluctuation or the yearly maximum range of water levels (YMXR). They used spectral analysis to explore relations between YMXR and an index of fish abundance determined from commercial fish catches over time. Spectral analysis treats a time series, such as the water level and commercial fish data, as a sum of sine waves (i.e., cycles; Priestly 1981). The method can be used to investigate changes in a variable over time and to detect cycles in a series. Other researchers have applied spectral analysis to fisheries data (Cohen and Stone 1987; Stone and Cohen 1990; Pereira et al. 1992). The method uses Fourier transform to fit a sum of sine waves, sine waves of different amplitude and period, to the data (Bloomfield 1976).

Two measures produced by spectral analysis are power spectrum and coherency. The set of amplitudes of a time-series at each possible period (years per cycle) is quantified by the power spectrum. Thus, the measure exposes significant cycles and

their periods. Coherency is a measure of the amount of correlation between the power spectrum of two time series. Analogous to the correlation coefficient, coherency indicates how closely two time series are fluctuating at a particular period. Coherency ranges from 0 to 1, where 1 represents perfect synchrony of fluctuations between two time series. A coherency is calculated for all periods explored in both time series. At each period then, the correlation between amplitudes of fluctuations gives the coherency. For example, high amplitudes at the same period in two time series would have high coherency at that period. For both measures some information is lost. Of importance here, information on phase relations or when the cycles peak is lost. The analysis ignores phase lags. For example, two time series composed of the same sine wave (same amplitude and period) could have different phases but still have a coherency of 1 at the period of that particular sine wave.

Results and Discussion

The results of the National Park Service research program and the Cohen and Radomski (1993) study are summarized in the following sections. Information gathered in earlier studies, which dealt almost exclusively with the fish community, and pertinent information from the literature are also included.

Water Quality and Primary Production

Water quality in Rainy Lake and the Kabetogama, Namakan, and Sand Point basins of Namakan Reservoir is good (Kepner and Stottlemyer 1988; Payne 1991). Rainy, Namakan, and Sand Point lakes, which receive most of their inflows from a large area of exposed bedrock and thin noncalcareous glacial drift, are oligotrophic to mesotrophic, having low dissolved solids and alkalinity (Table 1; Payne 1991). Kabetogama Lake receives much of its inflow from an area that is overlain by calcareous glacial drift and is eutrophic, having higher dissolved solids and alkalinity (Table 1; Payne 1991). Values for trophic state condition estimators (e.g., specific conductance, chlorophyll *a* concentrations, and carbon assimilation rates) from Kabetogama Lake are typically 2 to 3 times higher than those from the three less productive lakes (Table 1; Kepner and Stottlemyer 1988).

Analysis with a total phosphorus mass-balance model indicated peak spring total phosphorus levels in Kabetogama Lake would be reduced from about 34 µg/L to 30 µg/L if the present rule curve were replaced by one approximating natural conditions (Kepner and Stottlemyer 1988). The authors attributed this to (1) a reduction in bottom areas exposed by drawdown and accompanying sediment-water interactions, (2) reduced nutrient inputs resulting from die-off of littoral vegetation, and (3) reduced nutrient concentrations because of volume changes. The authors, stressing the model was uncalibrated, concluded a return to natural fluctuations could reduce phytoplankton biomass and the accompanying primary production. These changes, in turn, could have ramifications throughout the food web.

Aquatic Vegetation

Naturally regulated Lac La Croix supported a more taxonomically and structurally diverse plant community at all depths; the greatest differences were evident in the plant assemblages from deeper water (Table 2; Wilcox and Meeker 1991). The effect of the less than natural water level fluctuation on

Table 1. Mean values for selected water quality and trophic state estimators for Kabetogama, Namakan, Sand Point, and Rainy lakes.

Variable	Lake			
	Kabetogama	Namakan	Sand Point	Rainy
Dissolved solids (mg/L)[a]	68.0	49.0	56.0	49.0
Total alkalinity (mg/L)[a]	40.0	15.0	17.0	15.0
Total P, August (µg/L)[a]	45.0	12.0	18.0	11.0
Conductance (µmhos/cm@25° C)[b]	84.0	45.0	50.0	47.0
Chlorophyll *a* (mg/m^3)[b]	9.3	2.7	4.0	3.3
Carbon assimilation (mg C/m^3/4h)[b]	29.4	13.2	13.8	12.9

[a]Payne (1991); mean concentrations for 1977–83.
[b]Kepner and Stottlemyer (1988); mean concentrations for 1985–86.

Table 2. Sums of the mean importance values for 26 of the most prominent plant taxa on transects 0.5, 1.25, and 1.75 m below the mean annual high water level of Lac La Croix, Rainy Lake, and Namakan Lake. Taxa were separated into morphologically similar groups (Wilcox and Meeker 1991).

Category	Lac La Croix			Rainy Lake			Namakan Lake		
	0.5	1.25	1.75	0.5	1.25	1.75	0.5	1.25	1.75
Thin-stem emergents	21.1	0.0	0.0	36.0	2.9	0.0	43.4	13.3	0.0
Mat-formers	25.4	0.0	0.0	8.9	7.2	0.0	33.6	46.4	12.4
Low rosettes	6.8	0.0	0.0	1.0	28.3	0.0	13.5	22.8	13.6
Low-growth aquatics	9.9	33.8	43.0	0.0	8.3	0.0	0.8	5.4	34.9
Erect aquatics	16.1	52.5	52.1	0.0	49.1	96.8	0.5	8.7	29.2
Total	79.3	86.3	95.1	45.9	95.8	96.8	91.8	96.6	90.1

Rainy Lake was most obvious on transects that were never dewatered. Only four plant taxa were present at that depth (1.75 m), and they were all erect aquatics (Table 2). On Namakan Lake, the effects were most apparent at the depth (1.25 m) that was exposed annually to the effects of desiccation and disturbance from ice formation in the sediments (Table 2). Those conditions favored the establishment of low rosette and mat-forming plant species, neither of which provides much structural diversity in the water column. Wilcox and Meeker (1991) concluded the macrophyte communities of both regulated lakes would benefit from a hydrological regime approximating that of Lac La Croix. They suggested such conditions would provide a more natural and structurally diverse macrophyte community that would provide more diverse habitats for aquatic fauna (Wilcox and Meeker 1992).

Benthos

Winter drawdown on Namakan Reservoir can dewater up to 25% of the reservoir bottom and can cause a massive layer of ice to be in contact with the substrate for periods exceeding 100 days (Kraft 1988). These effects typically extend to levels 2 to 3 m below summer pool elevation. Mean diversity values for invertebrates at depths of 1 and 2 m in Namakan Reservoir were significantly lower than in Rainy Lake (Wilcoxon Signed Ranks test $P \leq 0.05$) but were not significantly different at 3, 4, or 5 m (Table 3). Equitability values, which indicate the evenness of allotment of individuals among taxa, exhibited a similar pattern (Table 3). Stranding and subsequent mortality, which were observed frequently in the winter samples, would seem to be a major contributing factor to the observed differences. Stranding of organisms (Benson and Hudson 1975) through exposure of substrates to air or ice cover (Ioffe 1966; Paterson and Fernando 1969; Kaster and Jacobi 1978) can reduce or alter benthic communities.

Individual taxa exhibited similar patterns, with densities of the alderfly (*Sialis* spp.), which is sensitive to lake level regulation (Grimas 1961), and mayfly (*Hexagenia* spp.) being lower in the drawdown zone in Namakan Reservoir than in Rainy Lake (Table 4). In contrast, chironomids, which quickly recolonize newly submerged areas (Cowell and Hudson 1968), were more abundant at the Namakan Reservoir sites than in Rainy Lake, particularly in the dewatered zone (Table 4). Isopods (*Asellus* spp.), which are also affected by regulation (Grimas 1961), were collected regularly in Rainy Lake but never in Namakan Reservoir.

Table 3. Mean diversity and equitability values for benthos samples from Rainy Lake and Namakan Reservoir on six common sampling dates, June 1984–June 1986 (Kraft 1988).

Depth (meters)	Diversity		Equitability	
	Rainy Lake	Namakan Reservoir	Rainy Lake	Namakan Reservoir
1	2.155	1.672	0.70	0.58
2	1.980	1.690	0.70	0.60
3	1.999	1.864	0.76	0.71
4	1.852	1.836	0.81	0.74
5	1.807	1.789	0.82	0.75

Results of a scuba survey of unionid mussels indicated the drawdown on Namakan Reservoir may have reduced their numbers and caused a shift in their distribution (W. L. Downing, Hamline University, St. Paul, Minnesota, personal communication). Mussel densities in Kabetogama and Namakan lakes were lower than in Rainy Lake and they occurred only at depths exceeding 4 m. In Rainy Lake, mussels were primarily found at depths of less than 4 m, which is more typical of bivalves (Pennak 1978). Conceivably, the drawdown could limit mussel populations either directly through death resulting from stranding or by forcing them to live in suboptimal habitats. Drawdown resulted in the stranding of large numbers of clams (Kaster and Jacobi 1978), and in Lake Sebasticook in Maine, drawdown caused two unionid mussel species to virtually disappear (Samad and Stanley 1986).

Shore and Marsh Nesting Birds

The large winter drawdown on Namakan Reservoir and the resultant low spring water levels make water level changes of more than 1 m necessary in May and June to reach the established summer levels. The June changes, in particular, adversely affected aquatic bird nesting success (Reiser 1988). During the period from 1983 to 1985, 47% of the attempted common loon nests on Namakan Reservoir were lost to flooding, while on Rainy Lake, 27% were lost. Red-necked grebes (*Podiceps grisegena*) were even more sensitive to lake level changes. From 1983 to 1985, 77% of the red-necked grebe nests on Namakan Reservoir were lost to flooding; on Rainy Lake 45% were lost.

Reproductive success of loons was significantly higher on Rainy Lake and Namakan Reservoir when the lake level rose less than 20 cm during June. On Rainy Lake, the mean productivity level for 3 years when the June lake level rise was less than 20 cm was 0.28 fledged young/adult; the comparable figure for 5 years when the rise was greater than 20 cm was 0.19. Reproductive success of common loons for the same time periods on the Namakan Reservoir lakes were 0.20 and 0.10 fledged young/adult. June lake level changes of less than 20 cm have occurred on Rainy Lake about 75% of the time since the 1970 rule curve went into effect, whereas on Namakan Reservoir such favorable conditions have only occurred about 20% of the time.

Similar relations were observed between lake level changes in June and the proportion of flooded nests of other marsh-nesting birds. Nest losses caused by flooding were higher for pied-billed grebes (*Podilymbus podiceps*) and black terns (*Chlidonias niger*), which nest on the water surface, than for red-winged blackbirds (*Agelaius phoeniceus*) and yellow-headed blackbirds (*A. xanthocephalus*), which nest above the water.

Aquatic Furbearers

High stable summer and early fall water levels caused beavers to build their lodges and food caches at elevations that left them susceptible to Namakan Reservoir's larger than natural winter drawdown (Smith and Peterson 1988, 1991). The winter drawdown forced nearly 80% of the beavers to abandon their lodges and food caches by January or February. As a result, beavers spent winter in woodchip nests under the ice outside their lodges and were forced to find alternative food sources. Although widespread mortality did not occur, weight loss was greater among Namakan Reservoir adults ($\bar{x}$ = 2.5 kg, N = 6) than adults from inland ponds and Rainy Lake ($\bar{x}$ = 1.4 kg, N = 7). Kit production was also lower in Namakan Reservoir ($\bar{x}$ = 2.1 kits/lodge, N = 16) than in more stable, inland ponds ($\bar{x}$ = 3.3 kits/lodge, N = 14). They were also more susceptible to predation, particularly in spring. Movement

Table 4. Comparison of mean numbers of three invertebrate taxa for six common sampling dates on Rainy Lake and Namakan Reservoir (Kraft 1988).

Depth (meters)	*Sialis* spp. Rainy Lake	*Sialis* spp. Namakan Reservoir	*Hexagenia* spp. Rainy Lake	*Hexagenia* spp. Namakan Reservoir	Chironomids Rainy Lake	Chironomids Namakan Reservoir
1	2.0	0.7	105.5	6.3	1,660	3,577
2	47.0	4.0	223.5	37.3	1,205	1,863
3	18.0	16.0	200.5	106.0	726	973
4	50.0	28.7	225.0	94.0	418	514
5	38.0	31.7	179.0	139.7	377	518

resulting from lodge abandonment, which was 100% when water was absent from lodge entrances in spring, exposed the animals to predation by gray wolves (*Canis lupus*). About 25% of spring mortality of beaver on the Namakan Reservoir lakes was attributable to wolf predation.

Effects on muskrats in Namakan Reservoir were similar, even though the animals abandoned houses and constructed new ones in deeper water as lake levels fell before freeze-up in October and November (Thurber et al. 1991). Even with this adjustment, the muskrat's primary food sources became inaccessible as water levels continued to fall throughout winter. The continued drawdown may have also led to increased predation by mink (*Mustela vison*). Errington (1939) found that muskrats foraged much more on top of the ice when burrows and houses became dry, increasing their exposure to predators. These limiting factors caused muskrat densities in Namakan Reservoir to be significantly lower than in Rainy Lake (Table 5).

The regulated lake levels affected river otters primarily by making shallow bays inaccessible during winter (Route and Peterson 1988). Summer observations of unmarked family groups and estimated home ranges of radio-tagged family groups indicated shallow, backwater bays were important as rearing areas. As winter drawdown proceeded and the ice collapsed onto the bottom of bays, river otter shifted their home ranges to deeper water. While these shifts occurred on both Rainy Lake and Namakan Reservoir, they seemed to be greater on Namakan Reservoir where winter drawdown was about 3 times larger.

Fish

Although about 50 fish species occur in Rainy Lake and Namakan Reservoir, concern about the effects of regulated lake levels on fish has centered on walleyes and northern pike because of their importance in the fishery. From the 1920's to the 1980's, they, along with lake whitefish (*Coregonus clupeaformis*), were the principal species in the commercial fishery on Rainy and Namakan lakes. Before 1960, the commercial harvest on Rainy Lake was usually greater than 300,000 kg/year (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, unpublished data). Since then, harvest has declined to about 100,000 kg/year. The commercial harvest on Namakan Lake from 1947 to 1980 averaged about 32,000 kg/year (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, unpublished data). During the 1980's, commercial fishing for walleyes and northern pike was eliminated from the Minnesota portion of Rainy Lake and was reduced substantially in Ontario waters. These two species are the primary species in the recreational fishery, which is a major component of the region's economy.

The principal concern has been the relation between lake levels during the spring spawning season and year-class strength of walleyes and northern pike. Investigations of this relation for walleyes in Rainy Lake have produced contradictory results. Johnson et al. (1966) and Chevalier (1977) found a positive relation between water levels at spawning time for walleyes and subsequent year-class strength in Rainy Lake. Chevalier's (1977) findings

Table 5. Comparisons of muskrat density by population estimates, trapnight success, and house counts for Kabetogama and Rainy lakes, 1985–87 (Thurber et al. 1991).

Variable	Kabetogama Lake		Rainy Lake	
	Mean	SE	Mean	SE
Population estimates[a]				
Fall 1985	0.25	0.05	0.93	0.14
Fall 1986	0.59	0.27	1.45	0.29
Trapnight success[b]				
Fall 1985	0.22	0.06	0.26	0.08
Fall 1986[c]	0.14	0.03	0.35	0.04
House counts[d]				
Winter 1985–86[c]	0.05	0.02	0.14	0.03
Winter 1986–87[c]	0.21	0.05	0.33	0.06

[a] Muskrats per hectare of emergent vegetation.
[b] Trapnight success = total captures ÷ total trapnights.
[c] Differences between Kabetogama and Rainy lakes were significant at $P < 0.05$.
[d] Muskrat houses per hectare of emergent vegetation.

were based on walleye year-class strength as determined from commercial gillnet catches of walleyes from the Minnesota and Ontario portions of the lake from 1948 to 1969. Osborn et al. (1981), however, found no significant relation between spring water levels and year-class strength of walleyes from commercial gillnet catches from the Minnesota portion of the lake from 1949 to 1980.

Osborn et al. (1981) also found no significant relation between spring water levels and year-class strength of walleyes from experimental gillnet catches in Kabetogama, Namakan, and Sand Point lakes. However, they did find a significant relation between the average rise in water levels during the spawning season and the subsequent abundance of 4-year-old northern pike in Kabetogama and Sand Point lakes.

These inconclusive results prompted the National Park Service to reassess the relation between spring water levels and year-class strength of walleyes and yellow perch in Rainy, Kabetogama, Namakan, and Sand Point lakes (Kallemeyn 1987a). Significant positive relations were found between spawning season lake levels and abundance of age-0 walleyes in all of the lakes except Namakan. Relations between lake levels and abundance of age-0 yellow perch were significant only in Sand Point Lake.

A positive relation was also observed between northern pike reproductive success and spring water levels in Kabetogama Lake (Kallemeyn 1987b). Reproductive success was higher when water levels reached emergent vegetation, which is preferred spawning habitat of northern pike (Fabricius and Gustafson 1958; Franklin and Smith 1963), in the 3-week period following ice-out. For emergent vegetation in Kabetogama Lake to be flooded during this period, however, water levels had to exceed the maximum levels called for under the 1970 rule curve.

Kallemeyn (1987a, 1987b) suggested a combination of an earlier spring rise in water levels and a summer drawdown would expand the area of wave-washed gravel and emergent vegetation at lower elevations and would enhance spawning success of walleyes, yellow perch, and northern pike. At present, these preferred spawning habitats occur at relatively high elevations because of the high, stable lake levels that are maintained throughout the summer and early fall on Rainy Lake and Namakan Reservoir. As a result, a substantial rise in lake levels, particularly on Namakan Reservoir, is required each spring to make these areas available for spawning. A summer drawdown, by providing spawning habitat at lower elevations, would reduce the amount of spring rise required to provide satisfactory spawning conditions. Such a change should be particularly beneficial in years when runoff is limited.

Cohen and Radomski (1993) found water level regulation has affected both the amplitudes and frequencies of annual water level fluctuations (YMXR). Dominating amplitudes in YMXR were evident at periods of 3 and 13 years (Fig. 4). At these two frequencies, greater than normal portions of the littoral area are exposed and then reinundated. For most frequencies, the power of the Rainy Lake YMXR time series was within the 95% C.I. of unregulated Lac La Croix's spectrum, while Namakan Reservoir's was largely outside. Since these lakes are in the same drainage, one would expect them to be synchronized or have similar spectra. This indicates the effect of water level regulation on YMXR is greater on Namakan Reservoir.

Significant coherencies were found between annual water level fluctuations (YMXR) and commercial fish catches on Rainy Lake and Namakan Lake (Cohen and Radomski 1993). On Rainy Lake, catches of lake whitefish and walleye were synchronized with YMXR at frequencies of 3–4 years (Fig. 5a). On Namakan Lake, lake whitefish catches were synchronized with YMXR at a frequency of 4 years (Fig. 5b). Cohen and Radomski (1993) also found that water level regulation, through its effects on YMXR, changed inter-specific interactions of fish in Rainy and Namakan lakes. Their results suggested that the fishery was more disturbed on Namakan Lake than on Rainy Lake, and that this was caused in part by water level regulation.

Cohen and Radomski (1993) concluded, as had Wilcox and Meeker (1991) in regard to aquatic vegetation, that the water management system should allow for variability in water levels. For assuring adequate fish habitat, they recommended that frequencies and amplitudes in the regulated lakes be allowed to correspond to those of Lac La Croix, the native dynamic.

In summary, most species and biological communities investigated in Rainy Lake and Namakan Reservoir have been affected by the alteration of the annual cycle in water levels as well as the reduction in year-to-year variability. The greatest effects were associated with the larger than natural water level fluctuations on the Namakan Reservoir lakes. The plants and animals have not been able to adjust to the changes in the magnitude and timing of lake

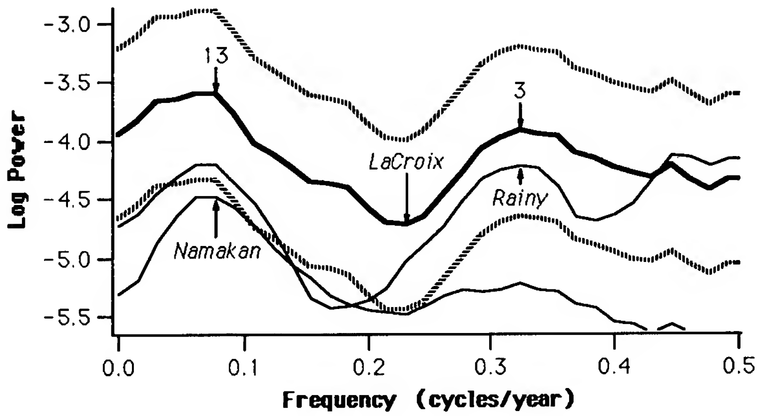

Fig. 4. Log power spectra for YMXR from Rainy Lake, Namakan Reservoir, and Lac La Croix. *Broken lines* indicate 95% C.I. *Numbered vertical arrows* indicate dominating periods (years per cycle; Cohen and Radomski 1993).

level fluctuations since the dams were constructed, and in particular to the water management program used since 1970.

Alternative Rule Curve Development and Assessment

We believe the best means of overcoming these biological problems is implementation of a water management program that more closely approximates the magnitude and timing of natural fluctuations in lake levels with which the affected species evolved. From the biological perspective, alternative regulatory programs should match the projected natural or predam fluctuations, albeit at the higher lake level stages associated with the dams. Year-to-year variability should be included in the hydrologic system. Simulation of natural hydrologic cycles is commonly used in wetlands management to benefit plants and animals and produce more typical marsh communities (Weller 1978; Ball 1985).

Our proposals probably should be considered goals because their complete implementation would likely result in conflicts with other water users. Limitations imposed by the continued presence of the dams and the necessity of meeting the needs of various users will likely restrict our efforts to rehabilitation rather than restoration of the ecosystem (Magnuson et al. 1980). Even with these limitations, however, it should be feasible to develop a water regulatory program that is more ecologically sound.

Embracing this philosophy, the National Park Service in 1990 developed 13 alternative regulatory programs, each consisting of a pair of rule curves—one for Rainy Lake and one for Namakan Reservoir (Kallemeyn and Cole 1990). Each alternative was analyzed with Flug's (1986) hydrology model to determine if the reservoir system could accommodate it under normal hydrologic conditions as well as under extreme high- and low-flow conditions. The model also provided projections of hydropower production.

An impact assessment matrix was used to relate the results of the environmental studies and the hydrology model analysis to potential effects of various alternatives. Ranking factors were developed for various biological attributes along with hydropower production, navigation, flood control, archeological resources, public beaches, and boat dock usability and susceptibility to ice damage, all of which would be affected by changes in rule curves. The ranking factors were then used to evaluate effects of alternatives on these attributes, with the results being entered into the matrix. The matrix integrated the information and facilitated discussions among the public and resource agencies.

As the National Park Service program proceeded in 1990, concerns continued to be expressed about the present water management program, particularly effects on navigation, flood control, power generation, and water access. Proponents for those uses, despite having influenced the alternatives analyzed by the National Park Service, felt the National Park Service preferred alternative did not adequately address their concerns and that it placed too much emphasis on ecosystem integrity. In 1991, a steering committee consisting of U.S. and Canadian representatives from private industry (the dam owner), the public, and the government formed to develop a consensus on how the waters of Rainy Lake and Namakan Reservoir should be managed. The committee's three objectives are to

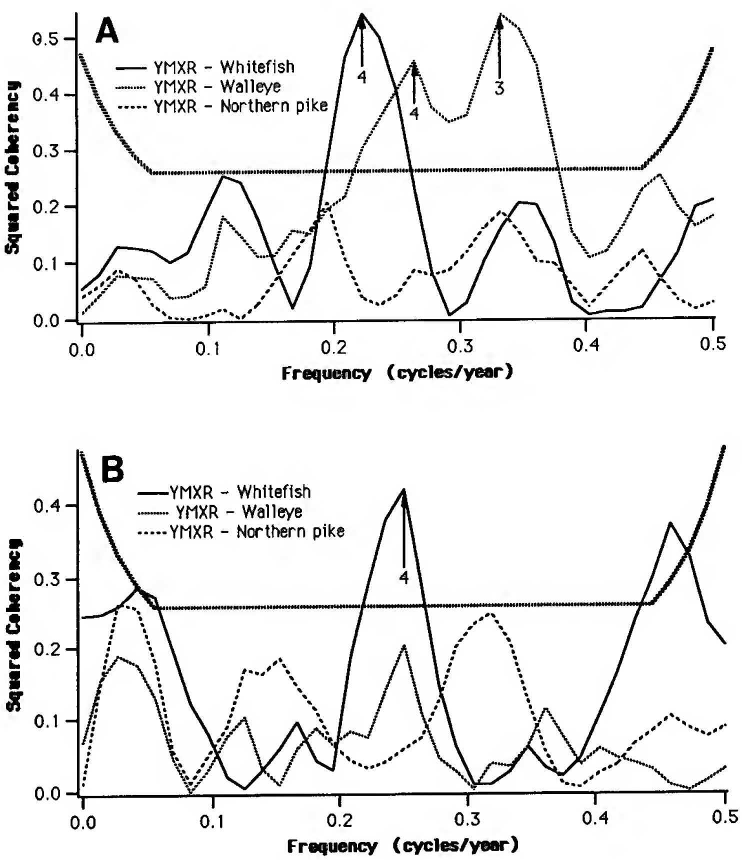

Fig. 5. Squared coherency between the residuals of the YMXR and species' series of commercial catches (kilograms) for the Minnesota portion of the South Arm, Rainy Lake(A), and for Namakan Lake(B). *Vertical arrows* indicate dominating periods (years per cycle). Values above the *broken line* indicate $P \leq 0.05$ significance (Cohen and Radomski 1993).

(1) provide a process for public involvement in discussions, (2) consider proposals for change, and (3) if in the public interest, submit a proposal for change in water level management to the International Joint Commission. Before any proposal is submitted to the International Joint Commission, it must undergo a public review process.

Conceivably, any plan submitted by the committee to the International Joint Commission could also be used by the dam owner to fulfill requirements of their Federal Energy Regulatory Commission license for the U.S. portion of the International Falls dam. The National Park Service and the Minnesota Department of Natural Resources, which are on the steering committee, are two of the three government agencies that the licensee is required to consult with in developing a management plan for Rainy Lake; the other is the U.S. Fish and Wildlife Service.

From 1991 to February 1993, the steering committee attempted to obtain consensus by addressing each representative's interests. The representatives, recognizing that some uses would conflict, agreed to use principled negotiation, which is a method for incorporating environmental policy into resource use conflicts (Fisher and Ury 1981). An integral component of this approach is identification of objective criteria for resolving conflicts. Historically, when environmental interests interacted with interests that used narrowly focused monetary costs as objective criteria, environmental concerns were devalued because of their inability to quantify costs, benefits, or losses. However, in the Rainy Lake–Namakan Reservoir negotiations, environmental interests were accepted because of the results of the research on those waters. Objective criteria that the committee used to develop and negotiate alternative water management programs included scientific judgment, monetary costs, and equal treatment of interests.

A comparison of two alternative rule curves provides an example of this process (Fig. 6). On the basis of the accepted criteria, the natural rule curve would rank high biologically because it approximates natural hydrologic conditions and addresses

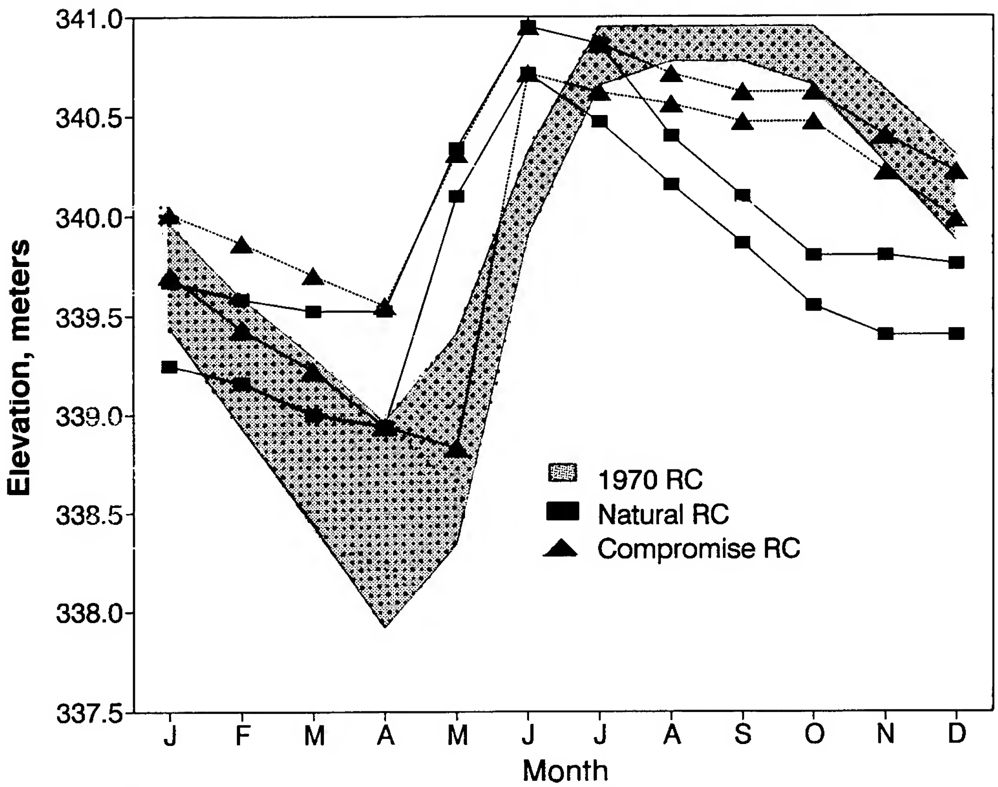

Fig. 6. Comparison of alternative rule curves with the 1970 rule curve for Namakan Reservoir.

many of the fish and wildlife concerns. However, because of the summer drawdown, it would rank low for navigation, dock usability, and hydropower production. The compromise rule curve, with its reduced summer drawdown, improves conditions for those attributes while still providing some improvement in biological conditions. Neither of these alternatives, however, addresses restoration of more extreme periodic fluctuations in lake levels.

Compromises will be necessary to balance competing needs of environmental and socio-economic interests. Implementation of environmentally sensitive rule curves will require shifts in priorities because historically, socio-economic uses were given precedence even though there was no legal mandate for such action. Incorporating some of the annual and long-term variability in water levels that is an integral component of an unregulated system will be particularly difficult. To incorporate that variability may require development of a forecasting system that will enable users that require a consistent source of water to adjust to changes in runoff and lake levels.

Any alternative water management plan submitted to the International Joint Commission should provide for postimplementation monitoring and research. Information from such programs is needed to determine if rule curve modifications can reduce negative effects on the aquatic ecosystem without seriously conflicting with other uses. Should that not be the case, the study results could serve as the basis for further modifications.

An alternative plan should also provide for the continued involvement of the many affected constituencies. Cooperation among various users seems to be the best means of convincing the International Joint Commission to develop and implement a water management program that protects the aquatic ecosystem and meets the needs of human users.

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Contaminants, Fish, and Hydrology of the Missouri River and Western Tributaries, South Dakota

by

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Abstract. We report on contaminants in sediments and biota, fish assemblages, and hydrology of the Missouri River and its western tributaries in South Dakota. Past mining activities and natural occurrences were identified as the primary contaminant sources in western rivers of South Dakota. Historical mining activities in the northern Black Hills discharged contaminants into streams, where they are still present. Elevated concentrations of arsenic and mercury related to ore processing activities were identified in the Whitewood Creek, the Belle Fourche River, the Cheyenne River, and the Missouri River, streams that sequentially flow into each other. Naturally occurring selenium from soil and rock formations was detected at elevated concentrations in sediments or biota in the Cheyenne River, Cheyenne River arm of Oahe Reservoir, Lake Francis Case, and Lewis and Clark Lake. Other contaminants detected above background levels were arsenic, barium, boron, chromium, mercury, manganese, nickel, and zinc. We make the following recommendations: (1) remediation of areas contaminated or affected by mine wastes—especially in the northern Black Hills—should continue, (2) monitoring of areas polluted with selenium should continue and environmental selenium should be confined to keep it from spreading, (3) siltation should be reduced by better land management in the watershed, (4) consideration should be given to increasing habitat diversity on the Missouri River in South Dakota, and (5) intensive fish sampling should be implemented on tributary streams to document current fish assemblages. Flow volumes in western Missouri River tributaries have historically fluctuated widely. Torrents of water flush through these streams following heavy precipitation events. The flows periodically drop to zero in all of the tributaries. Fish seemingly concentrate in deep pools during periods of low flow or move downstream to the Missouri River. The Missouri River provides a refuge for tributary stream fish during adverse periods. Fish species diversity in these

streams has decreased since samples were first collected before 1955, as compared with samples taken in 1980.

South Dakota is a relatively unpopulated state. It has only 696,004 residents according to the 1990 census. The distribution of people in South Dakota is polarized, with large populations located near Sioux Falls in the east and Rapid City in the west. The small amount of industry in the state is mostly located near these cities. Environmental contaminants associated with industry have the greatest potential to be found in the extreme eastern or extreme western parts of the state. Central South Dakota contains little manufacturing and is relatively contaminant free.

The Missouri River bisects South Dakota from north to south. All of the rivers in South Dakota flow into the Missouri River. The major tributary streams in the western part of the state flow from west to east before joining with the Missouri. These rivers flow mostly through relatively contaminant-free grassland areas used for hay production and grazing. However, there are contaminants in parts of the Black Hills and in some Black Hills streams. Contaminants can be transported great distances by water, and this study shows that contaminants found in western South Dakota are also present in the Missouri River.

There are three sources of contaminants in South Dakota: naturally occurring elements; industry, including mining; and agriculture. The greatest potential contaminant threat in western South Dakota to fish and wildlife is from inorganic chemicals such as arsenic and mercury produced by past Black Hills mining activities, and naturally occurring selenium.

Only limited studies have been conducted on the effects of contaminants in biota on fish distribution and abundance in western South Dakota streams. Evaluation of contaminants, hydrology, and biota in a watershed is needed to support management decisions.

The objectives of this paper are to identify contaminant distribution in sediment and biota, describe changes in fish assemblages, identify fluctuations in hydrologic conditions, and determine the biological significance of these variables in five principal watersheds associated with the Missouri River and its western tributaries in South Dakota.

Study Area

Major Contaminants

The Black Hills are located in extreme western South Dakota (Fig. 1). The Black Hills are, for the most part, contaminant-free and include 459,200 ha of National Forest and 234 km of trout streams. Industrial pollution is not a threat to most of the area. The creeks in the Black Hills generally consist of clear, cold, pollution-free water that flows over rock or gravel beds.

Mine wastes have caused water quality problems for some northern Black Hills streams for decades. Gold Run Creek, which contained a heavy load of mine wastes, flows into Whitewood Creek between the towns of Lead and Deadwood. Whitewood Creek was a clear, cold trout stream before becoming polluted with mine wastes. It is currently classified as a semipermanent warmwater stream. Whitewood Creek has a continuous water supply. Homestake Mine diverts water from Spearfish Creek for its own use and for Lead and Deadwood. Return flows from the mining company and the two towns, along with water from natural watershed flows and ground water from the Homestake Mine, all make up Whitewood Creek flows.

Large quantities of mining, milling, and ore processing wastes entered Whitewood Creek between 1875 and 1977 from mines operating in the northern Black Hills around Lead, South Dakota (Horowitz and Elrick 1990). About 100 million metric tons of mine tailings containing elevated concentrations of arsenic, mercury, and cyanide have been dumped into Whitewood Creek. In 1970, the U.S. Environmental Protection Agency revealed that 5.4 to 18.2 kg Hg/day were in the mine tailings slurry discharged into Whitewood Creek (U.S. Environmental Protection Agency 1971a).

Homestake Mining Company, the largest mine operator in the Black Hills, discontinued mercury use in December 1970. Homestake plant effluents still contained 1.13 kg Hg/day. Analyses of Homestake's effluent in June 1971 showed that daily loads of 141 kg of cyanide, 109 kg of zinc, 33 kg of copper, and about 3,000 tons of suspended solids were discharged into Whitewood Creek (U.S. Environmental Protection Agency 1971a).

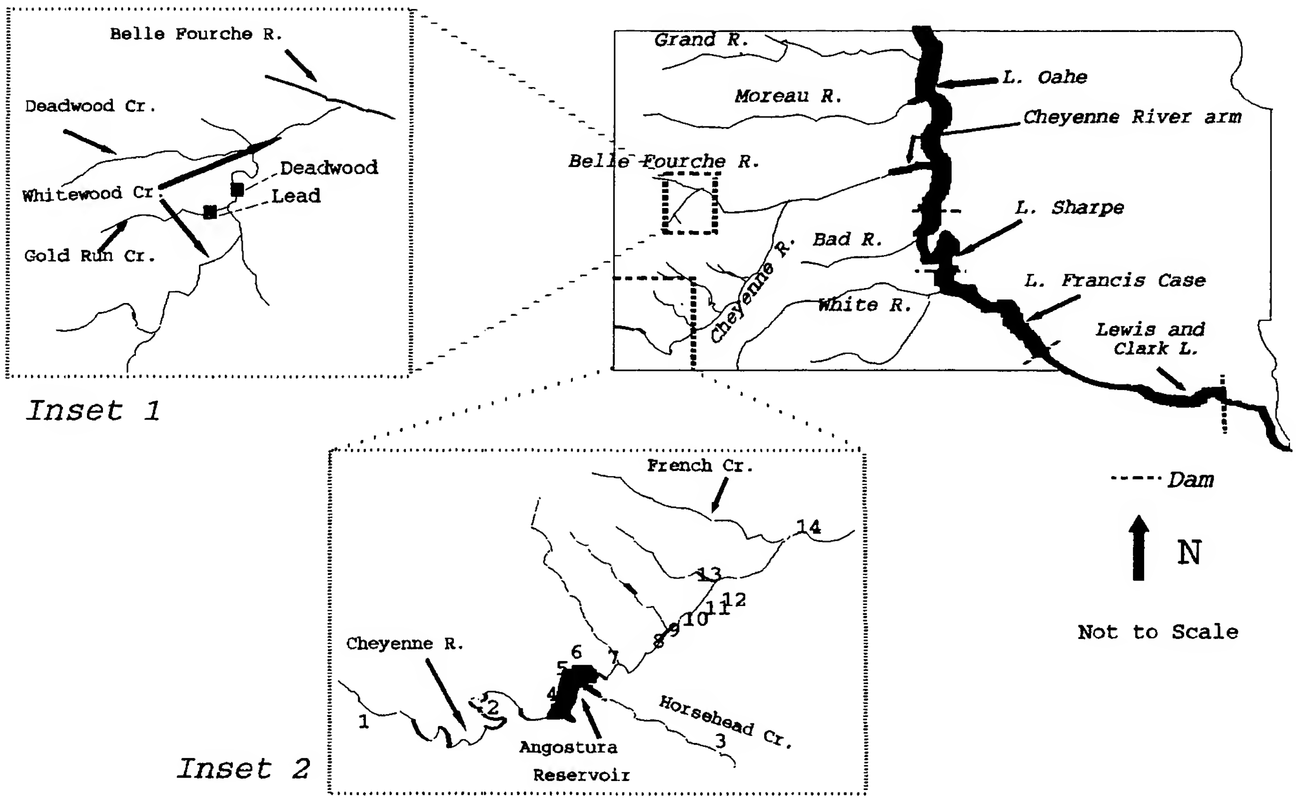

Fig. 1. Study area in western South Dakota. *Inset* 1 shows the Gold Run and Whitewood Creek drainages and the mining area in the northern Black Hills. *Inset* 2 shows numbers identifying fish and sediment sampling locations on the Cheyenne River.

In December 1977, Homestake constructed a dam across Whitewood Creek at Grizzly Gulch in an attempt to trap mine tailings and reduce pollutants downstream (U.S. Environmental Protection Agency 1990). However, mine tailings previously deposited along the Whitewood Creek banks continue to slough off into the creek.

Many Black Hills creeks have headwaters at higher elevations, drain easterly toward the foothills, and empty into either the Cheyenne or Belle Fourche River. Gold Run Creek enters Whitewood Creek near Lead, South Dakota. Selenium is not a wide-spread contaminant problem in the Black Hills; however, elevated selenium concentrations (6.9 μg/g) from an unknown source were detected in sediments at the mouth of Gold Run Creek (U.S. Geological Survey 1990).

Whitewood Creek flows northeast from the towns of Lead and Deadwood and enters the Belle Fourche River about 50 km to the northeast (Fig. 1). The Belle Fourche River is the largest stream in the northern Black Hills area. The same contaminants discharged into Whitewood Creek have been detected at elevated concentrations in the Belle Fourche River (Roddy et al. 1991).

Mining occurred in the vicinity of Custer, Hill City, and Silver City in the southern Black Hills, but mercury was not widely used and is not a problem in the southern Black Hills. Selenium is not elevated in the southern Black Hills, but it is elevated in the prairie to the south.

The portion of the Cheyenne River watershed located south of Edgemont, South Dakota, contains marine shale that has elevated concentrations of selenium (Harris 1991). This selenium has been detected at relatively high concentrations in fish from Angostura Reservoir (Greene et al. 1990). Selenium is the only contaminant known to be elevated in the sediments and biota in the part of the Cheyenne River that receives drainage from the southern Black Hills.

The Cheyenne River is the largest western Missouri River tributary in the state. It flows northeasterly around the southern and eastern borders of the Black Hills and then merges with the Belle Fourche River about 80 km east of the Black Hills.

After merging with the Belle Fourche River, the Cheyenne River flows through sparsely populated badlands and prairie before entering the Cheyenne River arm of Oahe Reservoir, about 160 km to the east. Inorganic contaminants are present in some sections of the Cheyenne River. Mine wastes that affect water quality are carried to the Cheyenne River by the Belle Fourche River.

The Grand and Moreau rivers are located north of and parallel to the Cheyenne River. Both of these rivers flow to the east across the prairie and enter Oahe Reservoir (Fig. 1). The Bad River flows mostly through unaltered grassland prairie and enters the upper reaches of Lake Sharpe near Fort Pierre, South Dakota.

The White River watershed includes the badlands but is composed mostly of natural prairie. It enters Lake Francis Case near Chamberlain, South Dakota. The White River gets its name from the presence of off-white-colored suspended sediments that wash into the river from the badlands and other parts of the watershed. The Grand, Moreau, Bad, and White River drainages are relatively pollution free compared with the Cheyenne and Belle Fourche rivers.

Fish Assemblages

Knowledge of fish populations, and their change over time, in western tributaries of the Missouri River within South Dakota is limited. Fishery data collected or summarized by Churchill and Over (1933) and Bailey and Allum (1962) provided the available information on the existence of fish species within these river basins before impoundment of the Missouri River mainstem in South Dakota.

Fish population studies on tributary river basins, following completion of Missouri River mainstem impoundments, were limited primarily to work conducted on individual reservoirs. Documented fish assemblages before 1955 were compared with populations present within the drainage since 1980 (Appendix Table 1). Sturgeons, paddlefish, percids, and various centrarchids, while not documented in each tributary in earlier works (Churchill and Over 1933; Bailey and Allum 1962), were known to be present in the Missouri River and were suspected of inhabiting all of these tributaries under certain flow conditions.

Hydrology

Flow volumes in the western tributaries to the Missouri River vary widely between seasons and between years, with long periods of low flow interrupted periodically by water torrents flushing rapidly through the systems during periods of snow melt and following heavy rains (Appendix Table 2). Flows can range from over bank full to dry at many tributary sites during a year. The Missouri River provides a refuge for tributary fish during periods of low flow. The fish escape to the larger river, wait out the adverse conditions, and return to the same or a different tributary when flows resume. After reservoir construction; however, the amount of river habitat suitable as a refuge for temporarily dislocated stream fish in the impounded sections of the Missouri River declined. The change in habitat and habitat diversity on the Missouri River is believed to be partially responsible for the decline in the number of fish species present in tributary streams.

Tributary streams provide spawning and nursery areas for fish that inhabit the mainstem Missouri River. The Grand, Moreau, and Cheyenne rivers were exclusive spawning grounds for goldeye, walleye, sauger, white sucker, and minnows (*Hybognathus* spp.) and major spawning areas for white bass, buffalo, and carp (Nelson 1980). Nelson reported that young fish production was strongly correlated with river flow volume, which flooded terrestrial vegetation during the spawning season.

Normal precipitation amounts for selected portions of South Dakota, based on data from 1951 to 1980, are shown in Fig. 2. Western South Dakota is arid. The Black Hills region receives the most precipitation of any part of the state west of the Missouri River, averaging 54.1 cm yearly (U.S. Geological Survey 1992). The southwest and central regions receive the lowest annual rainfall, 42.21 and 42.93 cm (Fig. 2). Most precipitation occurs during the period April–June. These precipitation patterns determine stream flows of the western Missouri River tributaries. Selected hydrologic and basin characteristics for Missouri River tributaries are shown in Appendix Table 2.

Methods

Sediments and Shale

Sediment samples were collected in 1980 from lakes Oahe, Sharp, and Francis Case and were analyzed as described by Phillips et al. (1987).

In 1984, sediment grab samples were collected, by U.S. Fish and Wildlife Service personnel, from

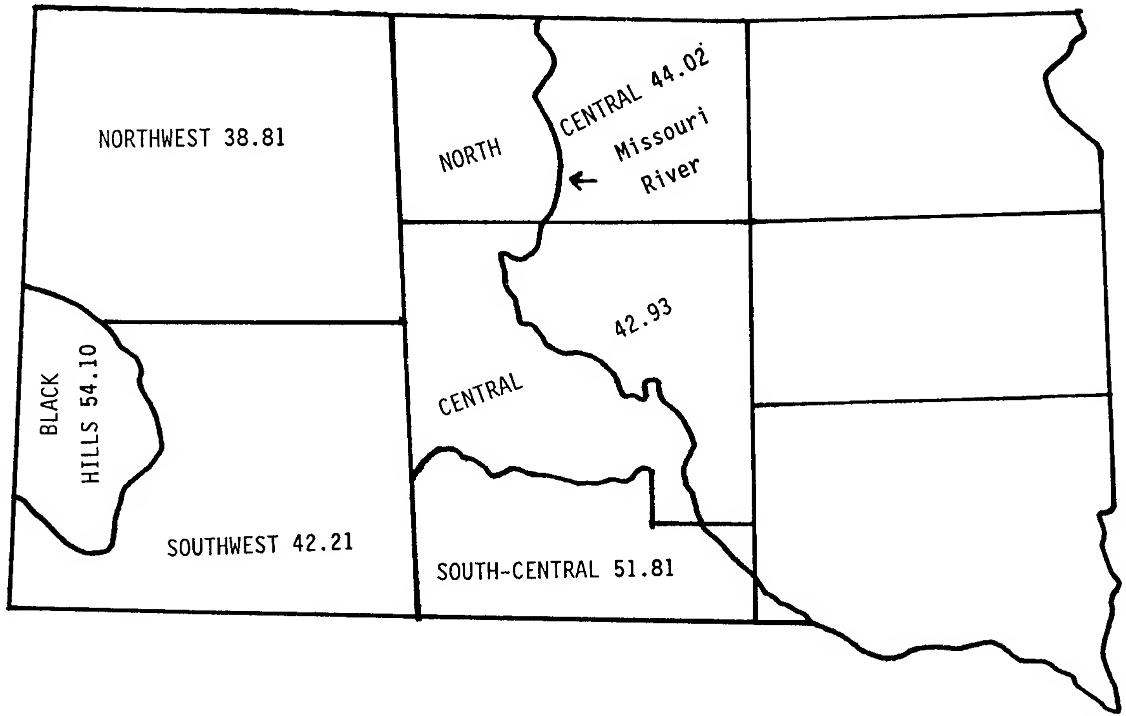

Fig. 2. Normal annual precipitation amounts in centimeters for selected regions of South Dakota (U.S. Geological Survey 1992).

a transect across Foster Bay on the Cheyenne River arm of Oahe Reservoir. Sediments were analyzed by the Environmental Trace Substances Research Center, Columbia, Missouri, for arsenic, mercury, and selenium.

In 1990, U.S. Fish and Wildlife Service personnel collected composite surface sediment samples from areas bordering Missouri River islands. Four to six subsamples were placed in an acetone-rinsed stainless steel bowl, mixed, then spooned into acid-cleaned glass jars and capped with teflon-lined lids for storage. Sediment samples were frozen at our laboratory and shipped on dry ice to the Research Triangle Institute, Research Triangle Park, North Carolina, where they were analyzed for arsenic, mercury, selenium, and nine other inorganic elements.

Cheyenne River sediments were collected and analyzed by the U.S. Geological Survey Geochemistry Laboratory, Lakewood, Colorado, as described by Greene et al. (1990). Sediment sampling locations on the Cheyenne River are identified in Appendix Table 3. Sediment samples from the Belle Fourche River were collected and analyzed as described by Roddy et al. (1991). Sediment sampling locations in the Belle Fourche River are described in Appendix Table 4.

In 1991, Service personnel collected sediment samples from two or more locations on the major western Missouri River tributaries. Collection locations were spaced so that the samples would be representative of sediments throughout the drainage. Sediment samples from tributaries were collected from the upper 10 cm of bottom substrate using a stainless steel scoop, a stainless steel spoon, or an Ekman dredge. Sediments were analyzed for 12 inorganic elements by the Hygienic Laboratory at the University of Iowa, Iowa City.

In May and June 1990, shale samples were collected from above the water line on six bluffs bordering Lewis and Clark Lake and the Missouri River. Bluffs sampled were selected based on size, accessibility, amount of exposed surface, and location. Unweathered shale samples were collected by digging 10 to 15 cm into the bluffs and removing a dry sample. Composite shale samples consisting of four to six subsamples each were stored in acid-cleaned jars capped with teflon-lined lids. Shale samples were analyzed for cadmium and selenium by the Research Triangle Institute.

Birds

Adult and juvenile double-crested cormorants (*Phalacrocorax auritus*) were collected from Foster Bay on the Cheyenne River arm of Oahe Reservoir using a shotgun. Livers were removed, frozen, and shipped to the Patuxent Wildlife Research Center, Laurel, Maryland, where they were analyzed for mercury and selenium.

Fish

The common and scientific names of fish referenced in this study are listed in Appendix Table 5. In 1970–71, northern pike, walleye, channel catfish, and common carp were collected in gillnets and trapnets from Foster Bay on the Cheyenne River arm of Oahe Reservoir, Whitlock Bay on Oahe Reservoir, and Oahe Reservoir tailwaters and analyzed for mercury by the U.S. Environmental Protection Agency, Kansas City, Missouri, as described by the U.S. Environmental Protection Agency (1971b). In 1984, northern pike, walleye, channel catfish, and common carp were collected from Foster Bay on the Cheyenne River arm of Oahe Reservoir and analyzed for mercury, arsenic, and selenium, as described by Sowards (1985).

Fish were collected from the Cheyenne River in 1985–86 and from the Belle Fourche River and Horse Creek in 1988 using electrofishing equipment. Fish sampling locations on the Cheyenne River and Belle Fourche River are described in Appendix Tables 3 and 4. Fish collected were from two different trophic levels—bottom feeders (shorthead redhorse, common carp) and pelagic feeders (flathead chub). Tributary stream fish were analyzed (whole body) for inorganic elements by the University of Missouri Environmental Trace Substance Research Center, Columbia, or by Hazleton Laboratories of America, Inc., Madison, Wisconsin.

In 1990, we used a seine to collect forage fish samples, consisting of emerald shiners, red shiners, spotfin shiners, and largemouth bass, from waters bordering Missouri River islands. The fish were stored in labeled food-quality plastic bags. Forage fish were analyzed (whole body) for 10 inorganic elements by the Research Triangle Institute.

All fish and the cormorant tissues were analyzed according to methods approved by the U.S. Environmental Protection Agency or the Patuxent Analytical Control Facility. Tissues and sediments were analyzed for arsenic and selenium by hydride generation, atomic absorption, and for mercury by cold-vapor atomic absorption spectroscopy. The other elements were analyzed by the inductively coupled plasma emission spectrometry method.

In 1967, the Service initiated a National Contaminant Biomonitoring Program (NCBP). Under the NCBP, fish were collected from randomly selected sites throughout the United States and analyzed for organic and inorganic contaminants. The NCBP provides baseline data for comparing contaminant concentrations in fish that are not related to toxicity values. Analytical results for our fish were compared with the NCBP 85th percentile data. Concentrations in fish are considered elevated when they exceed the 85th percentile of the nationwide geometric mean (Lowe et al. 1985).

Results and Discussion

Whitewood Creek

Sediments

Low background concentrations of arsenic (20.0 μg/g), mercury (0.19 μg/g), and selenium (1.20 μg/g) were present in Whitewood Creek sediments collected upstream from Lead between 1986 and 1988 (U.S. Geological Survey 1990). Concentrations of these elements were elevated in sediments collected downstream from Lead—maximum concentrations were 23,500 μg/g of arsenic, 1.73 μg/g of mercury, and 6.05 μg/g of selenium.

Fish Contaminants

In 1971, brook trout, white sucker, and longnose dace collected from Whitewood Creek upstream from its confluence with Gold Run Creek contained <0.04 μg/g wet weight of mercury (U.S. Environmental Protection Agency 1971a). In this same study, no aquatic organisms were found in Gold Run Creek or in Whitewood Creek downstream from its confluence with Gold Run Creek. The U.S. Environmental Protection Agency (1971a) reported that cyanide, arsenic, mercury, and suspended solids were each elevated enough so that independently or combined they could damage Whitewood Creek biota. Damage to biota extended into the Belle Fourche River downstream from the mouth of Whitewood Creek.

Belle Fourche River

Sediments

Concentrations of arsenic in sediments from unpolluted areas generally seemed to be less than 10 μg/g (Martin and Hartman 1984). Arsenic concentrations in Belle Fourche River drainage sediments ranged from 5.9 to 370.0 μg/g (Appendix Table 6) and were highly elevated compared with western U.S. soils (Shacklette and Boerngen 1984), northern Great Plains soils (Severson and Tidball 1979), or wetlands in the northern prairie region of the United States (Martin and Hartman 1984). The highest concentration of arsenic (370 μg/g) was detected in sediments at site 18 (Belle Fourche River near Sturgis).

Boron, cadmium, lead, and molybdenum concentrations in sediments from all Belle Fourche River stations were within the normal range reported for western U.S. soils (Shacklette and Boerngen 1984). Zinc, manganese, and nickel were elevated in sediments at most sites. At site 12 (Horse Creek above Vale), chromium and selenium were elevated in sediments, and at site 18, manganese, selenium, and nickel were elevated compared with values reported for western U.S. soils (Shacklette and Boerngen 1984).

Selenium in Belle Fourche River sediments ranged from 0.6 to 3.5 μg/g. Sediment samples from all sites had selenium concentrations below the 4.0-μg/g level of concern for bioaccumulation (Lemly and Smith 1987).

Mercury concentrations in all Belle Fourche River drainage sediment samples (Appendix Table 6) were low and less than or near the geometric mean concentration reported for western U.S. soils (Shacklette and Boerngen 1984).

Fish Contaminants

Arsenic is a nonessential element. Exposure to arsenic can reduce growth or increase mortality in aquatic organisms (Oladimeji et al. 1984). Arsenic is rapidly excreted after exposure (Eisler 1988); therefore, there is evidence that it does not readily bioaccumulate (Moore and Ramamoorthy 1984). Elevated concentrations of arsenic have, however, been documented in trout (Osmundson 1992; T. Chapman, South Dakota Department of Game, Fish, and Parks, personal communication).

In the Belle Fourche River, arsenic concentrations were relatively low and less than the NCBP 85th percentile concentration of 0.22 μg/g wet weight or about 0.88 μg/g dry weight (Lowe et al. 1985) in fish from all stations except for 12 and 18 (Appendix Table 7). Arsenic was highest in fish from station 18, where concentrations ranged from 1.3 to 7.6 μg/g (dry weight).

In fish tissues, mercury concentrations in excess of 1.10 μg/g wet weight should be considered evidence of an environmental mercury problem (Eisler 1987). For the protection of piscivorous mammals and birds, total mercury concentrations in their foods should probably not exceed 0.10 μg/g wet weight for birds and 1.10 μg/g wet weight for small mammals (Eisler 1987). The NCBP geometric mean for mercury in fish is 0.10 μg/g wet weight (0.40 μg/g dry weight; Schmitt and Brumbaugh 1990). For the Belle Fourche River, most fish from stations 2 and 12 (Appendix Table 7) had mercury concentrations below 0.40 μg/g dry weight, which is the maximum dietary concentration for the protection of birds. Most of the fish from station 18 had mercury concentrations that exceeded the NCBP geometric mean (Appendix Table 7).

Selenium concentrations in fish from station 2 on the Belle Fourche River (Appendix Table 7) were close to the NCBP 85th percentile concentration of about 2.8 μg/g dry weight (Lowe et al. 1985).

Most flathead chub from station 12 had selenium concentrations near or greater than the NCBP concentration of 2.8 μg/g. However, selenium concentrations in most of the shorthead redhorse from station 12 were close to the NCBP concentration. Common carp and shorthead redhorse from station 18 had selenium concentrations that exceeded the NCBP concentration (Appendix Table 7).

Cadmium in 10 Belle Fourche River fish samples slightly exceeded the NCBP 85th percentile dry weight concentration of about 0.36 μg/g (Lowe et al. 1985). Concentrations of copper and zinc in common carp from the Belle Fourche River exceeded the NCBP 85th percentile dry weight concentrations of about 4.56 μg/g and 185.04 μg/g, respectively. Common carp normally accumulate much higher concentrations of zinc than do other fish from the same water (Lowe et al. 1985).

Lead concentrations in most fish samples from the Belle Fourche River were below the NCBP 85th percentile dry weight concentration of about 1.28 μg/g (Lowe et al. 1985). Lead concentrations in only one fish sample slightly exceeded the NCBP geometric mean.

Cheyenne River

Sediments

Cadmium was present in sediments at only one of nine sites on the Cheyenne River at a detection level of 2.0 µg/g (Appendix Table 8). Arsenic concentrations in Cheyenne River sediments were elevated (6.2 to 15.0 µg/g) compared with geometric means reported for western U.S. soils (Shacklette and Boerngen 1984).

Mercury in Cheyenne River sediments was detected in seven of nine samples; however, the concentrations detected were all low (≤0.04 µg/g). Selenium in sediment samples from all Cheyenne River drainage sites was below the 4 µg/g level of concern for bioaccumulation (Lemly and Smith 1987), except at sites 8 and 13, where 4.30 µg/g and 14.00 µg/g, respectively, were detected. Barium concentrations in Cheyenne River sediments exceeded the values reported for western soils by Shacklette and Boerngen (1984) at all sites except 4, 6, and 13. Concentrations of barium, lead, manganese, nickel, and zinc (Appendix Table 8) were higher at most Cheyenne River locations than those reported for western U.S. soils (Appendix Table 9) by Shacklette and Boerngen (1984). Concentrations of molybdenum in the Cheyenne River sediments from most sites were below those reported for western U.S. soils.

Fish Contaminants

All but one fish from Cheyenne River stations 1 and 12 and most fish from station 14 had arsenic concentrations equal to or less than the NCBP 85th percentile value of 0.88 µg/g dry weight (Appendix Table 10). Mercury concentrations in all but seven Cheyenne River fish were less than the 0.40-µg/g NCBP geometric mean value (Appendix Table 10). The Cheyenne River drains some areas that are known to be high in selenium (Harris 1991). The highest selenium concentrations (2.1 to 10.0 µg/g) detected in this study were in Cheyenne River fish. Selenium concentrations in fish from all Cheyenne River stations exceeded the NCBP 85th percentile concentration of about 2.8 µg/g dry weight (Lowe et al. 1985).

Cadmium was not detected in 19 of 60 fish samples analyzed from the Cheyenne River (Appendix Table 10). Cadmium concentrations in only five fish samples from the Cheyenne River were greater than the NCBP 85th percentile dry weight concentration of about 0.36 µg/g. Copper concentrations in 20 of 60 Cheyenne River fish samples exceeded the NCBP 85th percentile dry weight concentration of about 4.56 µg/g. In flathead chub and shorthead redhorse, copper concentrations were lower (with the exception of one shorthead redhorse) than the NCBP concentration. Zinc concentrations in most common carp exceeded the NCBP 85th percentile dry weight concentration of about 185 µg/g. In flathead chub and shorthead redhorse, zinc concentrations were all lower than the NCBP concentration.

Fish Assemblages

Thirty-one fish species (Appendix Table 1) were historically documented (Churchill and Over 1933; Bailey and Allum 1962) from the Cheyenne River drainage, which included over 320 km of coldwater streams (South Dakota Department of Natural Resources 1975). All trout species, common carp, golden shiner, largemouth bass, and plains killifish are nonnative to the drainage. Koth and Ford (1980) sampled the upper portion of the basin and collected 15 species (Appendix Table 1), all previously documented. Fish collections from the adjacent Missouri River since 1980 (Riis et al. 1988; Johnson et al. 1991) documented 15 of the nontrout species identified in the earlier collections. Four species, finescale dace, longnose sucker, sicklefin chub, and sturgeon chub, are currently on the state's threatened list (Ashton and Dowd 1991).

Grand River

Sediments

Arsenic, manganese, and nickel in sediment samples from the Grand River (Appendix Table 11) exceeded the geometric means for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, and cadmium were not identified in sediments from the Grand River at the detection level.

Fish Assemblages

Thirty-two species of fish (Appendix Table 1) were documented from the Grand River drainage before 1955 (Churchill and Over 1933; Bailey and Allum 1962). All fish collected, with the exception of bluntnose minnow, common carp, and largemouth bass, were considered native to the drainage. In post-1980 samples from the Grand River, Riis et al. (1988) and Johnson et al. (1991) reported 21 of the same species known to be in Lake Oahe before 1955 (Appendix Table 1). Two species, the

sturgeon chub and sicklefin chub, are on the state threatened list, while the pallid sturgeon is listed on state and federal endangered species lists. The fate of the other eight species is unknown.

Moreau River

Sediments

Arsenic and nickel in sediment samples from the Moreau River (Appendix Table 11) exceeded the geometric mean for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, cadmium, and lead were not identified in sediments from the Moreau River at the detection level.

Fish Assemblages

Churchill and Over (1933) and Bailey and Allum (1962) collected 16 fish species from the Moreau River basin (Appendix Table 1). Ten of the fish species reported from the Moreau River basin also have been reported from the adjacent waters of Lake Oahe since 1980 (Riis et al. 1988; Johnson et al. 1991).

Bad River

Sediments

Copper, manganese, and nickel in sediment samples from the Bad River (Appendix Table 11) exceeded the geometric mean for these elements in western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, lead, and cadmium were not identified in sediments from the Bad River at the detection level.

Fish Assemblages

Nine fish species were historically documented (Churchill and Over 1933; Bailey and Allum 1962) from the Bad River, and an additional 17 species were reported from the Missouri River near the Bad River confluence (Appendix Table 1). Riis et al. (1988) and Johnson et al. (1991) sampled after 1980 and collected 17 of the fish species reported in the Bad River before 1955. The sicklefin chub, reported before 1955, is currently on the state's threatened list, while the pallid sturgeon, documented as present in the 1980's (J. Riis, South Dakota Department of Game, Fish, and Parks, personal communication), is rare and a state and federal endangered species (Ashton and Dowd 1991).

White River

Sediments

Inorganic element concentrations in all sediment samples from the White River (Appendix Table 11) were near or below the geometric mean for western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Mercury, selenium, lead, and cadmium were not identified in White River sediments at the detection level.

Fish Assemblages

Twenty-five fish species were documented in the White River basin before 1955 (Appendix Table 1). All species, with the exception of brown trout and common carp, were considered native to the basin. Twelve of the native species documented in earlier studies have been collected from the White River since 1980 (Johnson et al. 1991); pearl dace, sturgeon chub, and sicklefin chub are currently on the South Dakota threatened or endangered list (Ashton and Dowd 1991). Additionally, finescale dace, listed as state-threatened, have been collected since 1980 (Johnson et al. 1991). Fish reproduction and populations in the White River are probably limited by low plankton production, resulting from extremely high turbidity (South Dakota Department of Natural Resources 1975).

South Dakota suffers from periodic droughts, resulting in lower stream flows that also could reduce the abundance and distribution of fish in streams such as the White River.

Missouri River

Sediments

Arsenic and mercury concentrations were elevated in sediments collected from Foster Bay on the Cheyenne River arm of the Oahe Reservoir in 1984 (Appendix Table 12). Maximum concentrations of mercury were higher than concentrations reported in sediments from the Whitewood Creek, the Belle Fourche River, and the Cheyenne River. Arsenic was higher in Missouri River sediments than in Cheyenne River sediments.

Arsenic concentrations in Missouri River sediments ranged between 1.8 and 9.2 $\mu g/g$ (Appendix Table 13). Arsenic concentrations in sediments from five of nine Missouri River locations were at

or slightly exceeded the geometric mean of 5.5 µg/g for northern Great Plains soils reported by Shacklette and Boerngen (1984). No mercury concentration in sediment exceeded 1.0 µg/g; however, concentrations at 10 of 21 stations sampled exceeded the geometric mean of 0.046 µg/g for northern Great Plains soils.

Lead concentrations in sediments at 3 of 14 Missouri River sites exceeded geometric means reported for western U.S. soils (Shacklette and Boerngen 1984) and northern Great Plains soils (Severson and Tidball 1979). Concentrations of barium, boron, copper, nickel, and zinc were low and below the geometric means reported for northern Great Plains soils (Severson and Tidball 1979).

Selenium concentrations in sediments exceeded the geometric mean of 0.23 µg/g for northern Great Plains soils at 11 of 21 sites sampled (Appendix Table 13). The highest concentrations of selenium in sediments were in lower Lake Francis Case and Lewis and Clark Lake (Phillips et al. 1987). Selenium in these lakes probably originated from local sources, such as marine shale deposits located in watershed soils and along shorelines.

The Missouri River islands, where sediments were collected in 1990 for analyses, are listed by river kilometer (Appendix Table 13). Selenium concentrations in sediments collected from around the islands ranged from less than 0.30 to 0.80 µg/g. Selenium and other inorganic chemicals were present at or near background concentrations in sediments collected in the vicinity of the islands.

Selenium is a naturally occurring trace element that is an essential nutrient in small amounts but becomes toxic at higher concentrations. Selenium is toxic at concentrations only slightly above required dietary levels (Ohlendorf and Skorupa 1989). It is highest in soils associated with coal deposits and marine shales. Selenium is easily leached from seleniferous soils by irrigation water or natural precipitation.

Cadmium and selenium were elevated in bluff shale samples collected in 1990. Selenium concentrations in shale samples ranged between 4.79 and 13.60 µg/g with a mean of 7.45 µg/g. Normal background concentrations of selenium in shale are about 0.16 µg/g (Eisler 1985b). Maximum selenium concentrations in the marine shales bordering the Missouri River are over 20 times higher than the background concentrations reported by Eisler (1985b).

Cadmium concentrations in shale samples ranged from 1.56 to 9.35 µg/g with a mean of 5.72 µg/g. Background cadmium concentrations in soils are 1.0 µg/g or lower (Eisler 1985a). The cadmium concentrations in shale (maximum concentration 9.35 µg/g) collected from the Missouri River bluffs were elevated compared with normal soil concentrations. Cadmium in the dry bluffs is biologically unavailable until it moves from the bluffs and enters the aquatic environment. Cadmium may enter and bioaccumulate in food chains under the right conditions. However, the fate of cadmium eroded from the bluffs is not known after it enters the Missouri River.

The shale bluffs bordering the Missouri River in southeastern South Dakota are eroded by wind and wave action. The unweathered shale falls into the water, where it is pulverized by waves, rocks, and ice. The physical alteration of shale may result in the transfer of inorganic contaminants from the shale to river water or sediments. Selenium may be oxidized and modified into a more bioavailable form that can enter local aquatic foods or wash downstream, where it settles out in slack-water areas. These slack-water areas are along stream borders or near islands that are important fish and wildlife habitats. The relocation of selenium from shale bluffs to slack-water areas downstream increases the possibility of aquatic organism exposure.

Birds

In a study by Ohlendorf et al. (1990), percentage moisture in 173 adult bird livers representing 16 different species averaged 70.16%. This percentage moisture in bird livers was used to convert wet weight selenium and mercury concentrations to dry weights for the birds we collected so that mercury and selenium could be compared with concentrations reported in the literature.

Mercury was elevated in the livers of adult double-crested cormorants collected from the Cheyenne River arm of Oahe Reservoir in 1984 (Appendix Table 14). Mercury in adult cormorant livers ranged from 1.90 to 36.00 µg/g wet weight. Mercury concentrations in juvenile cormorant livers were much lower than in adults and ranged between 0.38 and 1.30 µg/g. Mercury concentrations in adult cormorants sampled for this study were highly elevated compared with the concentrations reported in the livers of other birds.

Mercury concentrations of 1.1 µg/g wet weight in liver or kidney should be considered as presumptive evidence of an environmental mercury problem (Eisler 1987). Mercury concentrations detected in adult cormorant livers in this study

were within the range reported to be lethal for other birds. Fimreite (1979) reported that 8.3% of 289 domestic chickens (*Gallus gallus*) died after mercury exposure, and 18 µg/g of mercury were detected in livers of the dead birds. Mercury concentrations of 17 to 20 µg/g were detected in the livers of red-tailed hawks (*Buteo jamaicensis*) that died after mercury exposure (Fimreite and Karstad 1971).

Mercury concentrations were higher in fish-eating birds than in other birds that frequented mercury-polluted habitats. Hesse et al. (1975) reported mercury concentrations of 92.4, 49.4, and 38.5 µg/g in livers of double-crested cormorants collected from the Cheyenne River in South Dakota. Mercury in livers of nine other birds they collected from the same area were low and ranged from 0.17 to 0.98 µg/g. They attributed the mercury source to past Black Hills mining activities.

Powell (1983) reported a range of mean mercury concentrations between 0.05 and 2.10 µg/g wet weight in the livers of nine different bird species from a control area. He reported a range of mercury values of 0.87 to 11.40 µg/g wet weight in livers of birds from a contaminated area. Fleming (1981) reported that mercury in livers of adult canvasbacks (*Aythya valisineria*) ranged from 0.02 to 0.63 µg/g wet weight. Mercury concentrations in birds sampled for this study were highly elevated compared with the concentrations reported in livers of other birds.

Selenium was elevated in livers of adult double-crested cormorants collected from the Cheyenne River arm of Oahe Reservoir in 1984 (Appendix Table 14). Wet weight selenium concentrations in livers of adult cormorants were higher than in the livers of juveniles, with concentration ranges of 7.20 to 21.00 µg/g and 1.30 to 6.70 µg/g, respectively (Appendix Table 14). Selenium concentrations in cormorants from the Cheyenne River arm of Oahe Reservoir were higher than those reported by Ohlendorf et al. (1988) for birds from control areas, but they were lower than concentrations reported in livers of birds from highly contaminated areas.

The mean background selenium concentration in birds from control areas was 8.3 µg/g dry weight in Ohlendorf et al.'s (1988) study. They reported that selenium concentrations in birds from contaminated areas averaged 94.4 µg/g dry weight. Selenium in adult bird livers changed significantly within and between years for birds inhabiting areas of high contamination. They reported little difference in selenium concentrations in livers between species for adult birds at control sites where levels of selenium in foods were normal.

The higher concentrations of mercury and selenium in livers of our adult birds may have been caused by elevated contaminants in their foods and longer exposure duration. However, presence in juvenile birds demonstrates that selenium and mercury are being accumulated from local foods.

When selenium and mercury are present together in bird tissues, the toxicity of each is reduced (Eisler 1987). The individual toxicity of selenium and mercury in Cheyenne River cormorant livers may have been counteracted by the other element's presence.

Fish Contaminants

Northern pike, walleye, channel catfish, and common carp were collected for inorganic chemical analyses from Foster Bay on the Cheyenne River arm of Oahe Reservoir in 1970–71 and in 1984 (Appendix Tables 15 and 16). Mean mercury concentrations in edible tissue from all fish were much lower in 1984 than in 1970–71.

In 1971, northern pike, walleye, channel catfish, and common carp collected from the upper Cheyenne River arm of Oahe Reservoir, Whitlock Bay, and Oahe Reservoir tailwaters were analyzed for mercury (Appendix Table 15). Mean mercury concentrations were higher in fish from the Cheyenne River arm than in fish from the other two locations. In general, mercury concentrations were highest in northern pike.

Mercury was not detected in composited samples of forage fish collected around Missouri River islands (Appendix Table 17). Selenium was elevated in forage fish, and concentrations in four of five samples exceeded the NCBP 85th percentile dry weight concentration of about 2.8 µg/g (Lowe et al. 1985). Cadmium, chromium, and zinc concentrations in forage fish were similar to the NCBP 85th percentile concentration. Lead was not detected in two forage fish samples, but exceeded the NCBP 85th percentile dry weight concentration of about 1.28 µg/g in three samples.

Background selenium concentrations in fish from contaminant-free water average about 2 µg/g whole-body wet weight (Eisler 1985b). The forage fish in our study were the size that would be selected as food by other fish and some birds. Ohlendorf and Skorupa (1989) cited studies conducted in the western United States showing that selenium pollution of waterbird food generally is

in the range of 5 to 50 μg/g dry weight. Selenium concentrations in forage fish in this study ranged between 2.28 μg/g dry weight (0.41 μg/g wet weight) and 4.82 μg/g dry weight (1.18 μg/g wet weight). The selenium concentrations in Missouri River forage fish are lower than concentrations reported in waterbird foods from contaminated areas. Selenium concentrations in Missouri River forage fish were, based on studies conducted on other species, below dietary levels of concern for waterbirds.

Conclusions

- Arsenic, mercury, and selenium were elevated in Whitewood Creek sediments.
- No fish were present in Gold Run and Whitewood creeks in the vicinity of Lead and Deadwood in 1971. Fish and other aquatic organisms are now present in Whitewood Creek.
- In the Belle Fourche River sediments, arsenic, zinc, manganese, and nickel were elevated.
- In the Cheyenne River sediments, concentrations of arsenic were elevated, and concentrations of barium, boron, manganese, nickel, and zinc were higher than background.
- Concentrations of selenium were elevated in Cheyenne River fish.
- Mercury was higher in fish from Foster Bay on the Cheyenne River arm of Oahe reservoir than in fish from Oahe Reservoir or from the reservoir tailwaters. Mercury concentrations in Foster Bay fish seemed to have declined between 1970–71 and 1984.
- Mercury and selenium in livers of adult cormorants from the Cheyenne River arm of Oahe Reservoir were higher than in livers of juvenile cormorants.
- Mercury in livers of adult cormorants collected from the Cheyenne River arm of Oahe Reservoir was much higher than mercury in livers of cormorants from control areas in other studies.
- Selenium in livers of adult cormorants collected from the Cheyenne River arm of Oahe Reservoir was higher than selenium in livers of cormorants from control areas, but lower than in birds collected from highly contaminated areas in other studies.
- Selenium in sediments was elevated in Gold Run Creek, Cheyenne River, Lake Francis Case, and Lewis and Clark Lake.

Recommendations

- Remediation of areas contaminated or impacted by mine wastes—especially in the northern Black Hills—should continue.
- Selenium is hazardous to fish and wildlife especially when it enters aquatic environments:
  1. Continue to monitor polluted areas. Aquatic habitats where selenium concentrations are elevated enough to cause wildlife health problems should be managed to prevent wildlife exposure. Fish and wildlife management efforts should be conducted on areas where selenium is not a problem, thereby attracting animals to clean sites.
  2. Confine environmental selenium to keep it from spreading. Shale bluffs containing selenium border the Missouri River and Lewis and Clark Lake. The shale sloughs off into the water making selenium available through aquatic foods. Rip-rapping or other bank stabilization techniques on parts of the shoreline would prevent selenium from entering the water.
- Siltation should be reduced by better land management in the watershed.
- Serious consideration should be given to increasing habitat diversity on the Missouri River in South Dakota and other areas throughout the drainage. Improved habitat diversity would be of great value to fish species for all life functions and to many wildlife species, including migratory birds, that use islands and shoal areas for resting and feeding. State and federal agencies should work cooperatively to develop a long-term plan for habitat restoration on the river.
- An intensive fish sampling program should be implemented on the tributary rivers to document current fish assemblages. Only two comprehensive studies of fish species diversity in western Missouri River tributary streams have been conducted, and these were in 1955 or earlier. Lack of current data makes evaluation of tributary fish populations difficult.

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Appendix Table 1. Fish species collected from five western tributaries to the Missouri River in South Dakota before 1955 (Churchill and Over 1933; Bailey and Allum 1962) and after 1980 (Koth and Ford 1980; Riis et al. 1988; Johnson et al. 1991). In 1980, Cheyenne River fish were collected from the upper basin; data for other streams are represented by fish collected from the Missouri River near its confluence with the tributary.[a]

	White River		Bad River		Cheyenne River		Moreau River		Grand River	
Common name[b]	1955	1980	1955	1980	1955	1980	1955	1980	1955	1980
Pallid sturgeon	?		?	X	?	?	?	?	X	?
Shovelnose sturgeon	?	X	X	X	?	X	?	X	X	X
Paddlefish	?	X	?	?	?	?	?	?	?	?
Shortnose gar	X	X	X	X	X	X	X	X	X	X
Goldeye	X	X	X	X	X	X	X	X	X	X
Brook trout					X					
Brown trout	X				X	X		X		X
Rainbow trout					X	X		X		X
Bluntnose minnow				X		X		X	X	X
Creek chub	X	X	X	X	X				X	
Common carp		X	X	X	X	X		X	X	X
Fathead minnow	X	X	X	X	X	X	X	X	X	X
Finescale dace		X			X					
Flathead chub	X		X		X		X		X	
Golden shiner				X	X	X		X		X
Lake chub					X					
Longnose dace	X		X		X		X			
Pearl dace	X									
Plains minnow	X		X		X		X		X	
Sand shiner	X	X	X		X	X	X	X	X	X
Silverband shiner	X									
Silvery minnow	X	X	X				X		X	
Sicklefin chub	X		X						X	
Stoneroller	X									
Sturgeon chub	X				X				X	
Blue sucker	X	X		X		X		X		X
Longnose sucker					X					
Mountain sucker					X					
River carpsucker	?	X	X	X	X	X	X	X	X	X
Shorthead redhorse	X	X	X	X	X	X	X	X	X	X
White sucker	X	X		X	X	X	X	X	X	X
Black bullhead	X	X	X	X	X	X	X	X	X	X
Blue catfish	X				X					
Channel catfish	X	X	X	X	X	X	X	X	X	X
Stonecat	X		X		X		X		X	
Burbot		X		X		X		X	X	X
Plains killifish					X					
Black crappie	?	X	X	X		X		X	X	X
Bluegill	X	X		X					X	
Green sunfish	X		X		X		X		X	
Largemouth bass		X		X	X	X		X	X	X
Orangespotted sunfish	?	X	X	X	X	X		X	X	X
Pumpkinseed	X		X						X	
White crappie	?	X	X	X		X		X	X	X
Sauger	?	X	X	X	?	X	?	X	X	X
Walleye	?	X	X	X	X	X	?	X	X	X
Yellow perch	?	X	X	X	X	X	X	X	X	X
Freshwater drum	?	X	X	X	?	X	?	X	X	X

[a] ? = not collected in pre-1955 work, but suspected to have at least seasonally used the drainage.
[b] Scientific names listed in Appendix Table 5.

Appendix Table 2. Selected hydrologic and basin values for the Grand, Moreau, Cheyenne, Bad, and White rivers, South Dakota.

River	Years of data	Maximum flow (cfs)	Minimum flow (cfs)	Mean flow (cfs)
Grand: Reach from confluence Cheyenne River to confluence Firesteel Creek	34	31,000	0	231
Grand: At Shadehill Reservoir	49	58,000	0	111
Moreau: Reach from confluence North and South Forks to confluence Thunder Butte Creek	49	26,000	0	131
Moreau: Reach from confluence Thunder Butte Creek to Whitehorse, South Dakota	38	27,000	0	209
Cheyenne: Reach from confluence Belle Fourche River to confluence Cherry Creek	30	41,000	0	610
Cheyenne: Reach from confluence Cherry Creek to Lake Oahe	32	55,900	0	800
Bad: Gage station near Midland, South Dakota	47	29,400	0	N/A
Bad: Gage station near Ft. Pierre, South Dakota	64	43,800	0	148
White: Reach from South Dakota–Nebraska line to confluence Blacktail Creek	49	5,200	0	53
White: Reach from Bear-in-the-Lodge Creek to confluence Little White River	50	21,700	0	267
White: Reach from confluence Little White River to confluence Missouri River	66	51,900	0	524

Appendix Table 3. Site collection locations for fish and sediment samples Cheyenne River drainage. Data from Greene et al. (1990). Site locations are for data in Appendix Tables 8 and 10.

Site	Location	Media
1	Cheyenne River near Edgemont, South Dakota	Fish
2	Cheyenne River near Hot Springs, South Dakota	Sediment
3	Horsehead Creek at Oelrichs, South Dakota	Sediment
4	Angustura Reservoir near Hot Springs, South Dakota	Sediment
6	Angustura Canal near Hot Springs, South Dakota	Sediment
7	Fall River at mouth near Hot Springs, South Dakota	Sediment
8	Cheyenne River upstream from Buffalo Gap, South Dakota	Sediment
10	Iron Draw near Buffalo Gap, South Dakota	Sediment
12	Cheyenne River near Custer County 656 Bridge	Fish
13	Cottonwood Creek near Buffalo Gap, South Dakota	Sediment
14	French Creek near Fairburn, South Dakota	Sediment and fish

Appendix Table 4. Site collection locations for fish and sediment samples, Belle Fourche River drainage. Data from Roddy et al. (1991). Site locations are for Appendix Tables 6 and 7.

Site	Location	Description	Media
2	Belle Fourche River upstream from Belle Fourche	Belle Fourche River upstream from Belle Fourche	Fish
3	Redwater River above Willow Creek at Belle Fourche	Redwater River—a major tributary to the Belle Fourche River	Sediment
4	Crow Creek near Belle Fourche	Background site on tributary to Belle Fourche River	Sediment
5	Inlet canal near Belle Fourche	Site is downstream from Crow Creek and upstream from Belle Fourche Reservoir	Sediment
6	Belle Fourche Reservoir near Belle Fourche	Submerged channel of Owl Creek in the Belle Fourche Reservoir	Sediment
7	Irrigation canal near Fruitdale	Irrigation canal leading from Belle Fourche Reservoir	Sediment
12	Horse Creek above Vale	Creek receives irrigation return flows	Sediment and fish
18	Belle Fourche River near Sturgis	Belle Fourche River downstream from irrigation return flow	Sediment and fish
19	Sulphur Creek near Newell	Background site	Sediment

Appendix Table 5. Common and scientific names of fishes in this report.

Common name	Scientific name
Pallid sturgeon	*Scaphirhynchus albus*
Shovelnose sturgeon	*S. platorynchus*
Paddlefish	*Polyodon spathula*
Shortnose gar	*Lepisosteus platostomus*
Goldeye	*Hiodon alosoides*
Rainbow trout	*Oncorhynchus mykiss*
Brown trout	*Salmo trutta*
Brook trout	*Salvelinus fontinalis*
Central stoneroller	*Campostoma anomalum*
Lake chub	*Couesius plumbeus*
Red shiner	*Cyprinella lutrensis*
Spotfin shiner	*C. spiloptera*
Common carp	*Cyprinus carpio*
Mississippi silvery minnow	*Hybognathus nuchalis*
Plains minnow	*H. placitus*
Sturgeon chub	*Macrhybopsis gelida*
Sicklefin chub	*M. meeki*
Pearl dace	*Margariscus margarita*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Notropis atherinoides*
Silverband shiner	*N. shumardi*
Sand shiner	*N. stramineus*
Finescale dace	*Phoxinus neogaeus*
Bluntnose minnow	*Pimephales notatus*
Fathead minnow	*P. promelas*
Flathead chub	*Platygobio gracilis*
Longnose dace	*Rhinichthys cataractae*
Creek chub	*Semotilus atromaculatus*
River carpsucker	*Carpoides carpio*
Longnose sucker	*Catostomus catostomus*
White sucker	*C. commersoni*
Mountain sucker	*C. platyrhynchus*
Blue sucker	*Cycleptus elongatus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Black bullhead	*Ameiurus melas*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*I. punctatus*
Stonecat	*Noturus flavus*
Burbot	*Lota lota*
Plains killifish	*Fundulus zebrinus*
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*L. gibbosus*
Orangespotted sunfish	*L. humilis*
Bluegill	*L. macrochirus*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*

Appendix Table 5. *Continued.*

Common name	Scientific name
Black crappie	*P. nigromaculatus*
Yellow perch	*Perca flavescens*
Sauger	*Stizostedion canadense*
Walleye	*S. vitreum*
Freshwater drum	*Aplodinotus grunniens*

Appendix Table 6. Concentrations (μg/g dry weight) of elements in Belle Fourche River drainage sediments. Data from Roddy et al. (1991). Site locations are identified in Appendix Table 4.

Site	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
3	7.50	440.00	1.60	<2.00	21.00	10.00	10.00	360.00	<0.02	<2.00	8.00	0.90	33.00
3	6.10	380.00	1.10	<2.00	32.00	11.00	11.00	390.00	<0.02	<2.00	13.00	1.00	35.00
4	25.00	110.00	3.60	<2.00	35.00	21.00	14.00	1200.00	<0.02	9.00	43.00	1.30	150.00
4	16.00	91.00	5.60	<2.00	55.00	25.00	12.00	770.00	0.02	5.00	36.00	1.20	110.00
5	16.00	720.00	0.60	<2.00	22.00	12.00	21.00	1800.00	<0.02	2.00	35.00	0.90	93.00
5	8.80	610.00	1.10	<2.00	43.00	18.00	18.00	1700.00	<0.02	<2.00	36.00	0.80	91.00
6	8.60	480.00	1.70	<2.00	39.00	15.00	16.00	590.00	0.02	<2.00	26.00	0.70	74.00
6	9.20	460.00	1.70	<2.00	40.00	16.00	15.00	610.00	<0.02	<2.00	27.00	0.80	75.00
6	7.80	480.00	1.70	<2.00	39.00	17.00	14.00	570.00	<0.02	<2.00	26.00	0.70	72.00
6	6.00	530.00	1.10	<2.00	36.00	14.00	13.00	580.00	<0.02	<2.00	19.00	0.60	59.00
6	5.90	530.00	0.90	<2.00	38.00	13.00	14.00	620.00	<0.02	<2.00	26.00	0.60	62.00
6	5.90	530.00	0.90	<2.00	36.00	13.00	13.00	580.00	<0.20	<2.00	21.00	0.60	60.00
7	59.00	820.00	1.40	<2.00	41.00	15.00	47.00	320.00	0.02	2.00	28.00	1.00	78.00
7	30.00	590.00	0.70	<2.00	54.00	16.00	13.00	220.00	<0.02	<2.00	27.00	0.90	72.00
12	39.00	1670.00	3.10	<2.00	46.00	21.00	18.00	1490.00	0.06	5.00	48.00	3.50	124.00
12	12.00	1140.00	2.90	<2.00	62.00	19.00	18.00	686.00	0.12	<2.00	37.00	2.80	104.00
18	180.00	800.00	2.40	<2.00	40.00	19.00	15.00	1310.00	0.10	3.00	33.00	1.70	89.00
18	370.00	927.00	2.90	<2.00	61.00	31.00	19.00	1770.00	0.20	<2.00	41.00	2.20	112.00
19	19.00	220.00	2.20	<2.00	54.00	22.00	19.00	1100.00	0.02	2.00	36.00	0.90	95.00
19	11.00	160.00	2.10	<2.00	62.00	21.00	19.00	730.00	0.02	<2.00	33.00	0.70	82.00

Appendix Table 7. Concentrations (µg/g dry weight) of elements detected in fish from the Belle Fourche River drainage, 1988. Data from Roddy et al. (1991). Site locations are identified in Appendix Table 4.

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
2	Flathead chub (3 fish)	71.10	0.60	7.30	2.00	0.30	2.00	3.30	<4.00	56.20	0.44	<1.00	2.00	2.80	92.40
2	Flathead chub	73.20	<0.10	3.50	<2.00	<0.40	<1.00	2.10	<4.00	16.00	0.08	<1.00	<3.00	2.40	99.40
2	Flathead chub (3 fish)	68.90	<0.20	4.00	<2.00	0.20	<1.00	4.40	<4.00	11.00	0.04	<1.00	3.00	2.00	88.00
2	Flathead chub	71.70	<0.10	2.10	<2.00	<0.40	<1.00	1.00	<4.00	4.60	0.05	<1.00	<3.00	1.50	73.50
2	Flathead chub	67.50	<0.20	2.30	<2.00	0.20	0.87	2.70	<0.90	3.20	0.05	<0.10	<0.80	1.50	71.20
2	Flathead chub	75.70	<0.20	5.40	<2.00	0.60	1.70	2.60	<0.90	45.60	0.11	0.20	2.00	2.30	121.00
2	Flathead chub (2 fish)	72.80	<0.20	3.70	<2.00	0.30	2.00	3.80	<4.00	23.60	0.06	<1.00	1.00	1.90	97.00
2	Shorthead redhorse (3 fish)	70.40	<0.20	6.90	<2.00	0.40	<1.00	3.30	<4.00	56.90	0.09	<1.00	<1.00	2.60	123.00
2	Shorthead redhorse (3 fish)	72.60	<0.20	4.70	3.00	0.30	<1.00	3.00	<4.00	51.80	0.17	<1.00	<1.00	2.50	101.00
2	Shorthead redhorse (3 fish)	71.40	<0.20	5.60	<2.00	0.50	<1.00	3.80	<4.00	73.80	0.13	<1.00	1.00	3.00	120.00
2	Shorthead redhorse	72.20	0.41	6.20	10.00	0.50	2.00	2.10	<4.00	44.70	0.14	<1.00	<3.00	2.70	101.00
2	Shorthead redhorse (3 fish)	71.20	<0.20	3.90	<2.00	0.40	2.00	3.20	<4.00	53.40	0.12	<1.00	2.00	2.40	127.00
2	Shorthead redhorse	71.60	0.20	7.10	12.00	<0.40	2.00	1.90	<4.00	73.60	0.11	<1.00	3.00	2.40	85.70
2	Shorthead redhorse	72.40	0.20	4.30	7.40	<0.40	3.60	1.50	<4.00	32.00	0.16	<1.00	<3.00	2.60	88.50
2	Shorthead redhorse	75.20	<0.20	7.30	3.00	0.49	1.40	3.51	<0.60	85.80	0.17	0.61	2.80	3.40	105.00
2	Shorthead redhorse	74.50	<0.20	6.50	<2.00	0.56	1.40	2.50	<0.90	61.30	0.28	0.30	2.00	2.90	89.40
2	Shorthead redhorse	72.00	0.20	4.90	16.00	0.60	3.00	2.30	<4.00	63.50	0.15	<1.00	<3.00	2.40	86.50
2	Shorthead redhorse	74.50	<0.20	3.80	<2.00	0.26	1.80	2.60	<0.60	50.60	0.40	0.20	1.80	2.20	92.10
2	Shorthead redhorse	75.90	<0.20	4.10	<2.00	0.32	1.50	2.50	<0.90	51.50	0.41	<0.10	<0.80	2.10	86.10
2	Shorthead redhorse	73.30	<0.20	4.50	<2.00	0.39	0.70	2.10	<1.00	69.90	0.36	0.20	<1.00	2.60	83.50
2	Shorthead redhorse	74.50	0.20	4.20	4.00	1.50	<1.00	2.70	<4.00	48.00	0.26	<1.00	<3.00	2.80	96.40
12	Flathead chub (3 fish)	69.00	0.30	16.00	<2.00	<0.02	1.80	2.96	0.50	55.40	0.09	<1.00	1.30	3.60	72.30
12	Flathead chub	72.90	<0.10	4.40	<2.00	<0.40	<1.00	2.00	<4.00	8.80	0.12	<1.00	<3.00	3.60	86.80
12	Flathead chub	76.00	<0.20	5.90	<2.00	0.10	1.80	2.50	<0.90	15.70	0.15	<0.10	0.90	4.10	92.50
12	Flathead chub	74.30	0.20	6.50	<2.00	<0.40	<1.00	2.10	<4.00	16.00	0.28	<1.00	<3.00	4.30	104.00
12	Flathead chub	75.20	<0.20	2.40	<2.00	0.20	1.60	2.40	<0.90	9.68	0.16	0.71	3.70	4.60	85.10
12	Flathead chub) (3 fish)	71.30	<0.20	3.60	<2.00	0.02	0.33	2.25	<0.40	11.70	0.08	<1.00	0.20	3.00	78.10
12	Flathead chub	67.80	0.30	3.80	<2.00	<0.02	0.60	2.00	<0.40	17.50	0.06	<1.00	0.35	3.80	64.50
12	Flathead chub	68.70	<0.20	2.10	<2.00	0.04	0.20	2.49	<0.40	10.50	0.24	<1.00	0.10	5.10	72.90
12	Flathead chub	72.10	0.10	4.70	<2.00	<0.40	2.00	2.20	<4.00	15.00	0.20	<1.00	<3.00	4.10	90.20

Appendix Table 7. *Continued.*

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
12	Flathead chub	69.50	<0.20	3.50	<2.00	0.03	0.56	2.45	0.40	27.30	0.09	<1.00	0.48	3.30	78.70
12	Shorthead redhorse	71.60	<0.20	7.20	6.00	<0.20	1.90	2.25	<0.40	65.00	0.10	<1.00	0.96	2.70	82.60
12	Shorthead redhorse	67.80	0.20	4.50	3.00	<0.02	0.41	2.28	<0.40	42.20	0.10	<1.00	0.30	1.80	64.30
12	Shorthead redhorse	66.60	<0.20	5.50	3.00	<0.02	0.30	2.10	<0.40	35.00	0.05	<1.00	0.20	2.90	58.30
12	Shorthead redhorse	71.40	0.30	4.80	15.00	<0.40	2.00	1.50	<4.00	38.10	0.16	<1.00	<3.00	2.80	79.00
12	Shorthead redhorse	73.70	0.37	6.80	16.00	<0.40	2.00	1.80	<4.00	34.00	0.21	<1.00	<3.00	2.50	67.00
12	Shorthead redhorse	70.50	0.20	4.30	17.00	<0.40	2.00	1.40	<4.00	48.80	0.16	<1.00	<3.00	2.50	67.10
12	Shorthead redhorse	69.70	<0.20	6.70	3.00	<0.02	0.74	2.32	<0.40	33.60	0.17	<1.00	0.30	2.40	56.80
12	Shorthead redhorse	69.30	0.20	7.70	3.00	0.05	1.40	2.71	<0.40	62.40	0.19	<1.00	0.98	3.00	56.60
12	Shorthead redhorse	72.30	<0.20	9.40	<2.00	0.10	2.60	2.40	<1.00	44.30	0.41	0.39	2.00	2.50	68.00
12	Shorthead redhorse	69.50	0.30	5.40	16.00	<0.40	3.00	1.70	<4.00	35.00	0.23	<1.00	<3.00	2.70	60.20
12	Shorthead redhorse	69.60	<0.20	3.30	3.00	<0.02	0.35	2.10	<0.40	25.80	0.18	<1.00	<0.10	2.10	63.00
12	Shorthead redhorse	71.10	0.60	9.40	<2.00	0.10	3.90	3.30	<1.00	54.30	0.32	0.20	2.90	2.90	69.40
12	Shorthead redhorse	72.40	<0.20	5.30	<2.00	0.20	1.30	2.70	<0.90	41.40	0.41	0.20	0.90	2.70	72.80
12	Shorthead redhorse	68.40	0.20	4.60	<2.00	0.13	<0.10	2.00	<0.50	38.10	0.66	<1.00	<0.10	2.50	58.60
12	Shorthead redhorse	71.00	<0.20	6.30	<2.00	0.10	1.40	2.59	<0.50	42.90	0.30	1.00	5.20	2.00	67.90
12	Shorthead redhorse	71.10	<4.90	84.00	<2.00	0.20	1.80	3.50	1.00	56.60	0.33	0.35	2.00	3.90	64.90
12	Shorthead redhorse	71.60	0.30	9.50	<2.00	0.20	1.80	3.10	2.00	40.00	0.39	0.35	2.00	2.40	67.00
12	Shorthead redhorse	77.00	1.20	35.00	4.00	<0.40	2.00	4.90	<4.00	67.80	0.70	<1.00	<3.00	3.10	75.60
12	Shorthead redhorse	69.30	2.20	20.30	<2.00	0.11	1.20	3.09	<0.50	75.40	0.21	<1.00	2.40	2.80	61.80
12	Shorthead redhorse	73.20	0.40	5.90	<2.00	0.15	0.83	3.27	<0.40	35.60	0.44	<1.00	2.40	2.90	60.50
18	Common carp	79.90	2.00	3.50	<2.00	0.11	0.56	6.12	<0.40	24.30	0.32	<1.00	0.63	3.90	358.00
18	Common carp	78.60	3.20	4.90	<2.00	0.09	0.71	6.06	<0.40	35.30	0.35	<1.00	0.87	3.20	255.00
18	Common carp	78.10	7.60	4.90	<2.00	0.34	0.81	5.96	<0.40	18.70	0.69	<1.00	0.75	4.60	601.00
18	Common carp	76.10	3.40	3.40	<2.00	0.14	2.80	5.21	<0.40	11.30	0.98	<1.00	1.40	5.30	355.00
18	Common carp	75.10	3.80	4.20	<2.00	0.23	1.50	4.85	<0.40	15.60	0.57	<1.00	0.71	4.80	359.00
18	Common carp	72.50	3.50	8.10	<2.00	0.44	2.80	4.76	<0.40	26.10	0.89	<1.00	1.50	4.70	154.00
18	Shorthead redhorse	69.20	1.30	4.90	<2.00	0.20	1.90	2.00	<1.00	79.80	0.39	0.92	4.50	3.40	61.10
18	Shorthead redhorse	70.30	3.00	5.10	<2.00	0.12	0.49	2.53	<0.50	47.40	0.58	<1.00	0.97	3.60	66.40
18	Shorthead redhorse	66.60	4.30	6.00	2.00	0.06	0.30	2.45	<0.50	70.90	0.35	<1.00	0.30	2.90	56.30
18	Shorthead redhorse	70.40	3.90	4.90	<2.00	0.06	0.39	2.67	<0.50	52.90	0.41	<1.00	0.45	3.80	57.60
18	Shorthead redhorse	71.50	2.20	3.40	4.00	<0.40	<1.00	1.70	<4.00	35.00	0.96	<1.00	<3.00	3.70	46.90
18	Shorthead redhorse	67.80	2.40	8.00	<2.00	0.20	2.40	2.50	<0.90	49.40	0.78	0.55	2.80	2.80	60.30
18	Shorthead redhorse	69.70	3.20	6.70	<2.00	0.20	2.80	2.30	<0.80	73.60	0.66	0.50	2.70	3.50	58.40
18	Shorthead redhorse	69.40	1.40	9.30	<2.00	<0.40	<1.00	1.80	<4.00	33.00	0.83	<1.00	<3.00	3.40	53.00
18	Shorthead redhorse	67.40	1.80	4.60	<2.00	0.20	2.00	2.20	<0.90	44.00	0.67	0.89	3.30	2.80	56.90
18	Shorthead redhorse	70.60	2.50	4.00	<2.00	<0.30	2.00	2.00	<4.00	33.00	0.75	<1.00	<2.00	3.80	50.00
18	Shorthead redhorse	69.10	2.20	8.40	<2.00	0.12	2.60	2.89	<0.50	72.80	0.91	<1.00	0.75	3.30	64.50
18	Shorthead redhorse	67.20	1.30	5.20	<3.00	0.40	2.10	3.40	<1.00	28.10	0.71	0.97	1.00	2.90	52.90
18	Shorthead redhorse	67.90	2.20	3.10	<2.00	0.17	1.10	2.36	<0.50	26.40	0.85	<1.00	0.30	3.10	50.90

Appendix Table 8. Concentrations (µg/g dry weight) of elements in 62-µm fraction of Cheyenne River drainage sediments,1988. Data from Greene et al. (1990). Site locations are identified in Appendix Table 3.

Site	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Zinc
2	7.60	700.00		<2.00	22.00	9.00	12.00	1100.00	<0.02	<2.00	15.00	1.00	49.00
	6.60	480.00		<2.00	20.00	7.00	12.00	780.00	<0.02	<2.00	9.00	0.60	39.00
	11.00	510.00		<2.00	23.00	8.00	12.00	1300.00	<0.02	<2.00	15.00	0.90	49.00
3	8.60	720.00	5.50	<2.00	64.00	23.00	55.00	470.00	0.04	<2.00	26.00	1.00	96.00
4	7.20	440.00	2.10	<2.00	85.00	26.00	23.00	360.00	0.04	<2.00	26.00	1.00	110.00
6	6.20	400.00	2.10	<2.00	47.00	19.00	28.00	730.00	<0.02	<2.00	24.00	2.10	67.00
7	12.00	760.00	1.20	<2.00	50.00	20.00	18.00	710.00	0.02	<2.00	19.00	0.90	76.00
8	13.00	720.00	1.80	2.00	72.00	28.00	18.00	770.00	0.04	4.00	35.00	4.30	120.00
10	8.90	930.00		<2.00	57.00	21.00	18.00	860.00	0.04	<2.00	23.00	1.60	90.00
13	15.00	150.00	7.30	<2.00	67.00	28.00	18.00	3400.00	0.04	<2.00	31.00	14.00	140.00
14	6.50	1200.00	1.40	<2.00	35.00	16.00	17.00	560.00	0.02	<2.00	15.00	0.60	58.00

Appendix Table 9. Soil element concentrations from the United States. Except as noted, concentrations are geometric means in µg/g. One percent equals 10,000 µg/g. Table adapted from Allen (1991).

Element	Western U.S. soils[a]	Northern Great Plains soils[b]
Aluminum	5.80%	5.60%
Antimony	0.47	NA
Arsenic	5.50	7.10
Barium	580.00	1,100.00
Beryllium	0.68	1.60
Boron	23.00	41.00
Cadmium	NA	NA
Chromium	41.00	45.00
Copper	21.00	19.00
Iron	2.10%	2.10%
Lead	17.00	16.00
Magnesium	0.74%	0.66%
Manganese	380.00	460.00
Mercury	0.046	0.023
Molybdenum	0.85	3.80
Nickel	15.00	18.00
Selenium	0.23	0.45
Strontium	200.00	NA
Tin	0.90	160.00
Vanadium	70.00	54.00
Zinc	55.00	63.00

[a] Shacklette and Boerngen 1984.
[b] Severson and Tidball 1979.

Appendix Table 10. Concentrations (μg/g dry weight) of elements detected in whole-body fish from the Cheyenne River drainage, South Dakota, 1988. Data from Greene et al. (1990). Site locations are identified in Appendix Table 3.

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nikel	Selenium	Zinc
1	Common carp	80.30	0.50	4.80	<3.00	0.46	<0.20	8.90	<0.50	47.10	0.19	0.42	0.90	2.70	277.00
1	Common carp	78.30	<0.20	9.20	<3.00	0.30	2.00	5.90	<4.00	50.90	0.23	<1.00	<1.00	3.20	289.00
1	Common carp	78.70	<0.20	6.60	<3.00	0.20	<1.00	6.40	<4.00	66.40	0.20	<1.00	<1.00	2.40	273.00
1	Common carp	79.50	<0.20	5.40	<3.00	0.40	<1.00	4.80	<4.00	34.20	0.21	<1.00	<1.00	2.80	283.00
1	Flathead chub	76.90	0.10	3.60	<3.00	<0.60	3.00	2.80	<5.00	33.70	0.22	<1.00	<2.00	5.00	133.00
1	Flathead chub	75.00	<0.20	4.10	<3.00	0.39	0.84	3.03	<0.50	34.40	0.15	0.20	5.70	3.80	129.00
1	Flathead chub	74.30	<0.20	3.90	3.00	0.20	<1.00	2.90	<4.00	12.00	0.16	<1.00	<1.00	3.10	94.20
1	Flathead chub	71.90	0.30	6.90	<3.00	<0.20	<1.00	2.40	<4.00	64.10	0.11	<1.00	<1.00	3.00	122.00
1	Flathead chub	72.10	0.30	14.50	<3.00	<0.30	4.20	3.20	<6.00	131.00	0.09	3.00	18.00	2.10	99.10
12	Common carp	77.40	0.50	9.50	3.00	0.17	1.10	5.51	<0.50	48.70	0.12	<1.00	0.70	5.20	266.00
12	Common carp	77.80	0.10	3.20	<3.00	0.14	0.87	4.60	<0.40	27.80	0.09	<1.00	0.72	6.60	219.00
12	Common carp	78.30	0.30	3.80	<3.00	0.12	1.80	6.00	<0.40	23.70	0.11	<1.00	0.97	6.40	212.00
12	Common carp	78.20	0.20	3.40	<3.00	0.15	1.10	5.32	<0.50	23.10	0.14	<1.00	0.91	5.50	288.00
12	Common carp	77.00	0.53	9.20	3.00	0.15	1.80	4.73	<0.50	42.80	0.09	<1.00	1.10	5.40	225.00
12	Common carp	77.00	0.40	14.50	3.00	0.11	1.20	4.89	<0.40	43.90	0.14	<1.00	0.69	5.90	222.00
12	Common carp	76.40	<0.20	3.80	<3.00	0.10	<0.10	3.97	<0.50	21.70	0.10	0.10	<0.30	5.20	222.00
12	Common carp	78.00	0.30	8.10	<3.00	0.18	2.00	5.48	<0.40	36.60	0.23	<1.00	1.10	8.00	391.00
12	Common carp	75.90	<0.20	2.00	<3.00	0.10	<0.60	1.90	<0.50	13.00	0.31	0.10	<0.40	3.60	101.00
12	Common carp	76.40	<0.20	1.10	<3.00	<0.50	3.00	4.50	<5.00	6.40	0.29	<1.00	<2.00	7.70	234.00
12	Common carp	75.40	0.30	8.00	<3.00	<0.60	<2.00	5.40	<5.00	14.00	0.92	1.00	<2.00	8.00	274.00
12	Common carp	75.50	0.65	10.60	<3.00	<0.60	<2.00	6.70	<5.00	6.70	0.25	<1.00	<5.00	6.90	266.00
12	Common carp	76.50	0.30	4.90	<3.00	<0.60	2.00	4.80	<5.00	20.00	0.46	<1.00	<2.00	7.80	277.00
12	Common carp	77.10	0.34	13.30	3.00	0.23	2.70	5.98	<0.50	37.90	0.53	<1.00	1.60	10.00	197.00
12	Shorthead redhorse	69.20	0.20	6.40	<3.00	<0.60	4.00	2.30	<6.00	73.20	0.13	<1.00	<2.00	5.40	69.00
12	Shorthead redhorse	70.70	0.31	5.40	<3.00	<0.50	3.00	1.80	<5.00	60.50	0.14	<1.00	<2.00	5.90	64.80
12	Shorthead redhorse	69.90	0.20	7.10	<3.00	<0.60	5.00	2.30	<6.00	89.30	0.14	<1.00	7.40	5.80	67.90
12	Shorthead redhorse	72.40	<0.10	6.40	<3.00	0.05	3.20	2.75	<0.50	82.70	0.14	<1.00	3.20	5.20	84.10
12	Shorthead redhorse	72.90	0.30	4.50	<3.00	0.04	0.56	3.74	<0.50	60.50	0.14	<1.00	1.00	4.10	79.50
12	Shorthead redhorse	72.90	0.20	4.60	3.00	0.05	1.40	2.65	<0.50	63.80	0.19	<1.00	0.70	5.00	81.50
12	Shorthead redhorse	69.70	<0.10	4.40	3.00	<0.06	4.20	2.63	<0.50	57.90	0.14	2.00	8.70	5.90	71.20
12	Shorthead redhorse	73.20	0.10	10.00	3.00	0.04	0.57	2.94	<0.50	63.20	0.14	<1.00	0.40	4.40	70.90
12	Shorthead redhorse	70.20	<0.20	5.40	<2.00	0.10	1.60	2.30	<0.50	63.10	0.17	<0.10	0.80	5.50	65.80
12	Shorthead redhorse	71.10	0.10	5.00	<3.00	<0.60	2.00	2.10	<5.00	47.80	0.18	<1.00	5.00	5.10	58.10
12	Shorthead redhorse	69.30	0.20	5.00	3.00	0.10	3.00	2.86	<0.50	57.20	0.21	<0.10	1.50	5.20	64.30
12	Shorthead redhorse	68.30	0.30	142.00	4.00	0.18	1.40	2.30	<0.50	82.70	0.19	<0.10	1.70	4.70	59.60
12	Shorthead redhorse	72.50	0.10	4.30	<3.00	0.07	1.40	6.74	<0.50	38.20	0.37	<1.00	1.70	3.40	72.90
12	Shorthead redhorse	71.90	0.60	8.60	3.00	0.20	1.50	3.00	<0.70	97.00	0.47	0.20	1.00	5.10	68.90
12	Shorthead redhorse	67.20	0.34	11.30	<3.00	0.13	3.40	2.59	<0.50	94.90	0.25	1.00	5.40	3.80	53.90

Appendix Table 10. *Continued.*

Site	Species	Percent moisture	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nikel	Selenium	Zinc
12	Shorthead redhorse	73.10	0.67	161.00	<3.00	0.11	4.60	3.63	<0.50	89.20	0.37	<1.00	3.40	5.80	64.80
12	Shorthead redhorse	68.30	0.97	11.10	<3.00	0.09	5.70	2.99	<0.50	65.10	0.30	2.00	11.00	4.70	57.10
14	Common carp	76.10	0.40	17.20	<3.00	0.17	0.30	5.10	<0.50	23.60	0.16	<0.10	0.60	5.60	307.00
14	Common carp	72.80	<0.20	4.80	<3.00	0.24	<0.10	3.69	<0.50	14.70	0.30	0.31	<0.30	3.50	345.00
14	Common carp	71.50	0.20	7.60	<3.00	0.17	2.20	4.49	<0.50	15.50	0.21	0.10	0.90	4.90	312.00
14	Common carp	79.00	0.31	8.00	4.00	0.09	1.30	5.59	<0.50	19.60	0.16	<1.00	0.83	5.30	401.00
14	Common carp	79.50	0.79	18.00	<3.00	0.40	1.60	5.98	0.60	36.30	0.48	<1.00	1.00	6.60	401.00
14	Common carp	82.80	0.55	12.80	<3.00	0.61	3.40	7.31	0.70	25.90	0.75	<1.00	1.70	6.60	248.00
14	Flathead chub	69.80	2.30	24.80	<3.00	0.10	0.62	3.00	1.00	55.10	0.08	4.00	0.40	3.90	88.50
14	Flathead chub	67.80	1.60	20.30	<3.00	0.10	2.30	2.70	0.70	45.60	0.11	2.30	1.20	3.30	93.20
14	Flathead chub	74.10	0.62	10.30	<3.00	<0.60	3.00	1.60	<5.00	15.00	0.17	<1.00	4.00	4.00	84.70
14	Flathead chub	71.50	1.80	28.20	<3.00	<0.60	6.00	3.10	<6.00	48.70	0.12	<1.00	3.00	4.10	93.40
14	Shorthead redhorse	70.30	0.10	23.80	<2.00	<0.04	4.20	2.74	<0.50	51.30	0.13	<1.00	2.40	4.10	78.60
14	Shorthead redhorse	70.30	<0.10	7.00	<3.00	<0.50	3.00	2.00	<5.00	47.30	0.22	<1.00	<2.00	5.30	71.00
14	Shorthead redhorse	70.90	0.30	9.80	<3.00	<0.60	2.00	2.20	<5.00	56.70	0.22	<1.00	2.00	4.30	67.60
14	Shorthead redhorse	71.20	0.10	9.50	3.00	<0.40	<1.00	2.60	<4.00	40.00	0.27	<1.00	<3.00	4.60	82.00
14	Shorthead redhorse	71.10	<0.10	12.90	<3.00	<0.60	2.00	2.00	<5.00	52.10	0.22	<1.00	3.00	3.70	77.50
14	Shorthead redhorse	70.20	0.30	11.30	3.00	0.28	2.40	2.80	<0.50	41.10	0.35	1.70	5.10	4.50	82.00
14	Shorthead redhorse	73.00	<0.10	7.50	<3.00	0.07	1.80	2.87	<0.50	71.70	0.13	<1.00	1.70	6.30	84.50
14	Shorthead redhorse	67.50	<0.10	2.30	<3.00	0.03	0.30	2.31	<0.50	41.40	0.13	<1.00	0.41	3.50	63.40
14	Shorthead redhorse	72.10	<0.20	12.00	3.00	0.19	1.60	2.40	<0.50	70.30	0.32	<0.10	0.80	3.80	80.90
14	Shorthead redhorse	68.20	<0.20	26.50	3.00	0.20	1.00	2.60	<0.50	73.40	0.49	<0.10	0.60	3.50	75.00

Appendix Table 11. Concentrations (µg/g dry weight) of elements detected in sediments from the Missouri River tributary streams in South Dakota, 1991.

Location	Arsenic	Barium	Boron	Cadmium	Copper	Chromium	Lead	Manganese	Mercury	Nickel	Selenium	Zinc
Grand River												
Highway 73	7.2	130.0	46.0	<2.0	11.0	2.3	21.0	720.0	<1.0	26.0	<1.0	55.0
West of Highway 63	17.0	170.0	43.0	<2.0	10.0	2.3	<10.0	610.0	<1.0	30.0	<1.0	68.0
Moreau River												
Highway 63	11.0	180.0	34.0	<2.0	9.8	2.5	<10.0	640.0	<1.0	28.0	<1.0	71.0
Highway 73	11.0	220.0	39.0	<2.0	8.1	2.3	<10.0	900.0	<1.0	28.0	<1.0	54.0
Bad River												
Ft. Pierre, South Dakota	7.6	470.0	35.0	<2.0	31.0	12.0	<10.0	1,900.0	<1.0	50.0	<1.0	130.0
Phillip, South Dakota	4.0	280.0	27.0	<2.0	16.0	12.0	<10.0	320.0	<1.0	22.0	<1.0	66.0
White River												
At Lake Francis Case	2.9	340.0	15.0	<2.0	7.9	4.8	<10.0	510.0	<1.0	8.7	<1.0	34.0
Highway 73	1.5	400.0	15.0	<2.0	7.3	4.4	<10.0	430.0	<1.0	11.0	<1.0	30.0

Appendix Table 12. Concentrations (µg/g dry weight) of mercury, arsenic, and selenium in sediments from Foster Bay on the Cheyenne River arm of Oahe Reservoir, 1984.

Mercury	Arsenic	Selenium
13.0	10.0	0.7
10.0	9.5	0.5
9.9	10.0	0.6
7.0	6.7	0.3
13.0	9.7	0.6
14.0	20.0	3.7
15.0	10.0	0.5
11.0	10.0	0.6
15.0	9.5	0.7
15.0	6.6	0.7
11.0	30.0	0.5
11.0	12.0	0.6
3.0	2.2	0.2
7.5	5.2	<0.2
16.0	9.8	0.5
5.5	7.0	0.2
7.4	3.9	0.3
10.0	13.8	<0.2
9.1	7.6	<0.2
10.0	50.0	0.3
8.8	39.0	0.4
10.0	65.0	0.5

Appendix Table 13. Concentrations (μg/g dry weight) of elements in sediments from the Missouri River in South Dakota.

Location	Arsenic	Barium	Boron	Cadmium	Copper	Chromium	Lead	Manganese	Mercury	Nickel	Selenium	Zinc
Lake Oahe												
Upper[a]									0.05		0.76	
Lower[a]									0.06		0.52	
Lake Sharp												
Upper[a]									0.06		0.64	
Lower[a]									0.07		0.77	
Lake Francis												
Case Upper[a]									0.02		0.46	
Lower[a]									0.06		2.78	
Lewis and Clark												
Lake[a]									0.05		2.32	
RKM 1221.2		534.00		0.55	8.32	21.90	20.60	740.00	0.59	16.00	0.59	40.30
RKM 1222.8	4.60	150.00	14.00	<2.00	5.20	4.50	<10.00	360.00	<1.00	17.00	<1.00	33.00
RKM 1230.1	9.20	120.00	13.00	<2.00	<5.00	3.80	<10.00	260.00	<1.00	14.00	<1.00	30.00
RKM 1271.9	5.60	170.00	21.00	<2.00	9.70	5.70	<10.00	1,100.00	<1.00	25.00	<1.00	52.00
RKM 1277.5		434.00		<0.05	5.44	16.20	14.00	548.00	0.80	14.00	0.80	32.00
RKM 1280.8		461.00		0.98	12.30	27.00	25.50	1,380.00	0.08	22.10	0.80	53.70
RKM 1284.0	5.20	120.00	14.00	<2.00	<5.00	2.50	<10.00	310.00	<1.00	12.00	<1.00	28.00
RKM 1285.6		346.00		<0.05	3.63	7.60	14.50	533.00	0.62	10.10	0.62	19.60
RKM 1288.8	7.30	120.00	12.00	<2.00	<5.00	2.80	<10.00	320.00	<1.00	12.00	<1.00	26.00
RKM 1338.7	7.40	84.00	12.00	<2.00	<5.00	3.60	<10.00	350.00	<1.00	15.00	<1.00	28.00
RKM 1340.3		570.00		0.74	4.33	17.50	20.80	524.00	<0.03	14.40	<0.30	32.90
RKM 1351.6	3.70	110.00	8.60	<2.00	<5.00	2.60	<10.00	320.00	<1.00	7.50	<1.00	21.00
RKM 1356.4	1.80	28.00	<5.00	<2.00	<5.00	<2.00	<10.00	120.00	<1.00	<5.00	<1.00	8.20
RKM 1370.1	8.70	160.00	15.00	<2.00	<5.00	3.40	<10.00	380.00	<1.00	15.00	<1.00	32.00

[a] Data from Phillips et al. (1987) showing the mean values for Mercury and Selenium in 13 to 30 sediment samples collected in 1980. Data by river kilometer (RKM) are for samples collected from the Missouri River islands in 1990 by the U.S. Fish and Wildlife Service.

Appendix Table 14. Concentrations (µg/g wet weight) of mercury and selenium in individual livers from adult and juvenile double- crested cormorants collected from the upper Cheyenne River arm of Oahe Reservoir in 1984.

	Mercury	Selenium
Adult	1.90	7.20
	36.00	21.00
	23.00	8.60
	26.00	14.00
Juvenile	1.20	3.10
	1.30	1.30
	0.83	4.10
	0.38	4.80
	0.59	6.70
	1.00	3.30

Appendix Table 15. Mean mercury concentrations (µg/g wet weight) in composite, edible tissue samples of northern pike, walleye, channel catfish, and common carp from Lake Oahe, 1970–71. Number of fish in parentheses. Data from U.S. Environmental Protection Agency (1971b)

Location	Northern pike	Walleye	Channel catfish	Common carp
Upper Cheyenne River arm of Oahe Reservoir	0.65 (12)	0.51 (18)	0.34 (14)	0.38 (18)
Whitlock Bay	0.40 (5)	0.16 (15)	0.23 (19)	0.22 (16)
Oahe tailwaters	0.20 (2)	0.12 (18)	0.21 (12)	0.15 (7)

Appendix Table 16. Mercury, arsenic, and selenium concentrations (µg/g wet weight) in whole fish and mercury in edible tissues of fish from Foster Bay on the Cheyenne River arm of Oahe Reservoir, South Dakota, 1984. Data from Sowards (1985).

	Percent moisture	Mercury	Arsenic	Selenium	Mercury in edible tissue
Northern pike	74.70	2.20	0.09	0.76	0.32
	71.50	0.16	0.16	0.75	0.15
	74.60	0.16	0.10	1.30	0.19
	74.90	0.14	0.21	0.85	0.09
	73.10	0.19	0.16	0.60	0.15
	70.70	0.16	0.12	1.00	0.14
	75.20	0.16	0.08	0.68	0.14
	74.70	0.13	<0.05	1.20	0.15
	72.30	0.27	0.07	0.62	0.17
	74.90	0.16	0.09	0.77	0.21
Mean[a]	73.66	0.37	0.11	0.85	0.17
Walleye	65.70	0.20	0.31	0.66	0.33
	70.40	0.25	0.26	0.49	0.30
	71.00	0.26	0.34	1.10	0.16
	69.80	0.20	0.25	0.85	0.12
	68.90	0.30	0.27	0.68	0.38
	67.40	0.21	0.31	0.66	0.19
	66.70	0.34	0.41	0.44	0.16

Appendix Table 16. *Continued.*

	Percent moisture	Mercury	Arsenic	Selenium	Mercury in edible tissue
	67.40	0.24	0.38	0.49	0.34
	72.90	1.70	1.50	1.20	0.17
	69.60	0.19	0.35	0.51	0.26
Mean[a]	68.98	0.39	0.44	0.71	0.24
Common carp	76.60	0.21	0.21	1.30	0.25
	77.20	0.15	0.17	1.90	0.34
	79.00	0.15	0.10	1.30	0.20
	73.80	0.12	0.18	1.40	0.16
	77.40	1.20	0.13	1.60	0.27
	78.40	0.18	0.12	1.20	0.16
	79.50	0.09	0.07	1.20	0.11
	78.10	0.23	0.07	1.60	0.25
	79.10	0.24	0.17	0.97	0.24
	69.30	0.18	0.25	0.96	0.34
Mean[a]	76.84	0.28	0.15	1.34	0.23
Channel catfish	75.80	0.08	<0.05	0.50	<0.05
	72.50	0.14	0.06	0.44	0.11
	64.20	0.12	<0.05	0.54	0.10
	82.80	0.07	<0.05	0.70	0.15
	78.10	0.10	<0.05	0.75	0.16
	74.20	0.23	<0.05	0.58	0.14
	79.00	0.06	<0.05	0.70	<0.05
	76.80	0.16	0.04	0.45	
	71.90	1.80	<0.05	0.33	0.35
	76.30	0.11	<0.05	0.48	
Mean[a]	75.16	0.29	0.03	0.55	0.13

[a] Half the detection level was used to calculate the means for elements not detected.

Appendix Table 17. Concentrations (mg/kg dry weight) of inorganic elements detected in forage fish collected in 1990 from islands on the Missouri River in South Dakota.

River kilo-meter	Percent moisture	Selenium	Mercury	Cadmium	Chromium	Copper	Manganese	Nickel	Lead	Zinc	Barium
1221.2	80.00	3.83	<0.05	0.194	2.47	4.55	93.20	2.24	1.60	120.00	51.10
1277.5	86.90	3.78	<0.05	0.135	6.22	3.05	120.00	3.29	<1.50	152.00	101.00
1280.8	81.70	2.28	<0.05	<0.010	2.33	2.90	170.00	4.85	2.47	91.30	38.50
1285.6	86.30	3.53	<0.05	0.565	3.66	4.12	411.00	4.43	3.47	149.00	195.00
1340.3	75.60	4.82	<0.05	0.180	1.62	2.93	24.30	0.50	<1.50	127.00	9.51

Resolving Resource Management Conflicts Between Listed and Unlisted Species on Large Rivers

by

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Abstract. Numerous examples exist of resource management conflicts that arise on large rivers with multiple listing of threatened or endangered species. Problems often develop when several listed species occupy different habitats within the same geographical region or when life requisite functions for more than one listed species overlap. Conflicts are also increasing between management for listed species and those that are not listed. Several processes have been used to help resolve such conflict, including multiple-species consultations between federal agencies, development of habitat conservation plans with nonfederal interests, and cooperative agreements between governmental agencies. Concepts for multiple-species listing and listing of threatened habitats are still in developmental stages. Resource managers and administrators are finding that developing an ecosystem approach to managing large rivers is a more effective way of addressing resource management conflicts among listed species and between species that are listed and not listed.

Environmental law plays a principal role in the welfare of fish and wildlife resources in this country by shaping nearly every land and water management decision (Rohlf 1991). As our population has increased and as we have become more sensitive to the world around us, environmental laws have proliferated to protect the public's rights to the public's resources (Berry and Keenlyne 1989). However, the strongest legal tool designed to conserve fish and wildlife biodiversity in the United States, the Endangered Species Act of 1973 (ESA), is often criticized as being flawed for focusing on individual species (Rohlf 1991).

Our collective task at this symposium is to look at restoration planning for rivers in the Mississippi River drainage system, with special focus on the Mississippi Interagency Cooperative Resource Agreement (MICRA). My specific task is to address possible means to avoid conflict among species listed under the ESA and between listed and nonlisted species.

Background

Early in my career, I noted that there are two kinds of biologists: lumpers and splitters. The philosophical division is not new and has been a major schism in science for millennia, with the prolonged but basic debate about which is greater—the part or the whole. Twenty-five years ago Commoner (1967), in his book "Science and Survival," likened the argument of supporting that the "part" is greater to what a sorcerer's apprentice might conjure up when acting dangerously on incomplete knowledge. He concluded that the biosphere, the "whole," is much greater than the sum of its parts and that modern technology

is too powerful for us to continue our present experiment on our own survival through a trial-and-error approach.

Protection of the biosphere, the whole, was paramount in Commoner's mind. Rohlf (1991) stated that even though the intent of the ESA is to protect biodiversity (i.e., the whole) through protection of critical habitats, implementation has focused on species, which has created problems. Thus, we observe the scientific debate between the lumpers and the splitters on yet another level, that is, protecting biodiversity or protecting species.

Within the last 5 years, much has been written about the functioning and preservation of large rivers. Once again, conclusions are that the whole is greater than the sum of the parts. Recent writings propose that we need to focus on river ecosystems and processes to address environmental concerns. The Proceedings of the International Large River Symposium (Dodge 1989), the Proceedings of the International Wetland Symposium on Wetlands and River Corridor Management (Kusler and Daly 1991), and the National Research Council work on restoration of aquatic ecosystems (1992) should be mandatory reading for every prospective large-river biologist.

Attempts at Conflict Resolution

Special management considerations for a single aquatic species that occupies a large range will almost inevitably engender conflict with requirements for other species. Special management or habitat development considerations for one species can also adversely affect other species that use the same system. Listed riverine species are commonly sympatric with other rare species and often occupy remnant river reaches together. On the Missouri River, the unchannelized and unimpounded remnant sections provide life requisite needs for several species. The endangered least terns and threatened piping plovers nest on the ever-diminishing sandbars, the endangered bald eagle finds winter roosts and feeding perches in the aging and dying cottonwood trees, and the endangered pallid sturgeon seeks food and suitable spawning conditions in the slowly degrading sections of the flowing river below the dams. Under such circumstances, where several species occupy the same remnant, natural river reaches, habitat modifications to benefit one species could affect the welfare of the other species. With four species having critical life requisite needs in three habitat types in the same remnant sections of a single ecosystem, conflict is highly probable without coordinated planning. If species become listed at different times and recovery planning for one is conducted independently of the others, conflicts can be expected.

Where several listed species occur in the same geographical area, multiple-species consultation (Section 7) under the ESA can be provided for federal agencies proposing or permitting actions. While multiple-species consultations help reduce the risk of adversely affecting one listed species at the expense of another, the process does not necessarily address the overall welfare of unlisted species that may occur in the area, nor the cumulative effects of proposed actions (Rohlf 1991).

In 1982, Congress amended the ESA to create a mechanism for reconciling conflicts. The amendment allows for an incidental take of a listed species provided that an approved habitat conservation plan to protect the species has been developed and accepted by all interests. The concept allows for the reduction of part of the habitat used by the species in question, or the accidental loss of a few individuals, providing the needs of a sustained population are provided for in an agreed to plan. The process is most often used where private development interests are planning a project in an area of important habitat for a listed species (Bean et al. 1991). Although a useful tool, the process is time consuming, often controversial, and often costly, and the broad-based public and private support necessary to accomplish the plan in the long run is difficult to obtain (Ruhl 1991). An examination of criteria to be used for habitat conservation planning indicates that the process is better suited for terrestrial situations than large rivers.

In recent years, agencies responsible for administering the ESA have encouraged multiple-species listing where several species may occur in the same area and have examined the concept of listing endangered habitats. The resultant multiple-species recovery plan would help resolve potential conflict among listed species using the same area and would begin the process of looking at the area as an ecosystem, which can help in avoiding conflict with other species. Multiple-species listing, however, is a difficult process because status data are required for each species, and the greater the number of species the greater the chance of public and political concern and backlash. Listing critical habitat is a separate and involved process that

almost invariably elicits backlash. The shortcomings of both processes are the high costs of time and staff. The multiple-species listing process, however, shows promise for special situations.

At present, the ESA is under reauthorization review, and modifications are being discussed to help avoid clashes between listed and unlisted species. The Studds-Dingell Bill, H.R. 4045, would reauthorize the ESA and direct the agencies that administer it to give priority to development of multi-species recovery plans. According to the Environmental Newsletter of the National Wildlife Federation, June 1992, the bill also directs that such plans promote recovery of the entire system. The proposed amendments obviously recognize the need for addressing the whole rather than the parts and could do much to alleviate conflicts between listed and nonlisted species by promoting ecosystem recovery plans.

The Mississippi Drainage and MICRA

There are more than 260 species of fish in the Mississippi River system (Robison 1986). An Executive Summary of the Comprehensive Strategic Plan for MICRA, produced and distributed by the American Fisheries Society, stated that MICRA has identified over 70 species of fish that are interjurisdictional species. Interjurisdictional fishery resources are defined by MICRA as "those fisheries and associated river ecosystems that depend on interjurisdictional rivers and come under the management of two or more governmental entities." The same document provides the mandate of MICRA: "to assess the Mississippi River drainage fishery resources and habitat requirements to protect, maintain, and enhance interstate fish species in the basin."

In the Mississippi drainage, the list of federally recognized threatened or endangered species includes mollusks, insects, plants, birds, mammals, and reptiles, in addition to 16 fish species. All of these species depend on the river systems and associated floodplains for their survival. MICRA needs to be ever alert that in focusing its efforts on 70-80 sport and commercial fish species that it does not subject itself to the same criticism levied against the ESA of being too narrow in scope by focusing attention on high-profile charismatic megafauna (Cairns and Lackey 1992) or in drawing attention away from a holistic approach to ecosystem protection by focusing on specific species (SFI Bulletin 423, April 1991, page 3).

The Future

Focusing on individual species is not only questionable policy but also impractical because adequate funding and manpower are unlikely to be available to protect endangered species one by one. Blackstein (1992) said that recovery of endangered aquatic biota must be accomplished through an ecosystem approach. Williams and Rinne (1992) stated that the primary goal for achieving biodiversity should be to preserve ecosystem integrity, that planning should be on an ecosystem basis, and that management should be for preserving ecosystem processes.

In 1991, in response to problems outlined above and concerns about a continuing need to add to the list of threatened and endangered species on the Missouri River, the U.S. Fish and Wildlife Service developed a proposal to facilitate optimal recovery of the natural resource values and environmental health of the Missouri River ecosystem. The primary objective was to establish an environmental resources management, restoration, and enhancement program that would involve interested governmental units and the public (Galat et al. 1993). In 1992, after receiving encouragement from other agencies and the public on its proposal, the U.S. Fish and Wildlife Service requested authorization and funding to begin work as a facilitator in developing an environmental restoration plan for the Missouri River. Action plans for restoration would be developed by river section by a multi-disciplinary team of river experts under memorandum of agreement. Restoration packages would be put together by river section through leveraging of agency programs and funds to accomplish goals of an overall restoration plan.

We, as a society, in the name of progress, have spent billions of dollars over the last 100 years in despoiling the functioning of our river systems. Our efforts have led to losses and reductions in biodiversity and the eventual listing of species under the ESA. The challenge to all of us is whether we can put the river systems back together and make the natural processes work. Law will continue to dictate land- and water-management decisions, but, as Rohlf (1991) warned us, the biologist can no longer afford to leave the welfare of rivers solely to the lawyers.

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Communication, Coordination, and Cooperation Among River Scientists, Decision Makers, and the Public—Their Use as a Management Tool on the Upper Mississippi River

by

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Abstract. This paper describes techniques used by biologists on the Upper Mississippi River to successfully organize themselves, gather information, and present that information to justify authorization and funding of a $200 million environmental management program. Techniques used are presented as recommendations that could be used by biologists on other rivers.

Communication, coordination, and cooperation are the main ingredients in any successful inter-group effort. They were used on the Upper Mississippi River to obtain funding for a $200 million Environmental Management Program in the late 1970's and early 1980's (U.S. Army Corps of Engineers 1990). This was at the beginning of a period of national economic conservatism and environmental exploitation, when there seemed to be little chance of success in passing any environmental legislation.

I was fortunate enough be one of the central figures involved in that success. It came as a result of extensive coordination and cooperation between five states and myriad federal and private interests. While our coordination efforts were complex, involving many individuals, the processes and techniques used were in many ways rather simple. We relied largely on common sense, what I often referred to as grade school politics, and the self discipline of a small group of close-knit, dedicated people.

Upper Mississippi River Conservation Committee

The concepts behind the Upper Mississippi River Environmental Management Program and its environmental monitoring component originated among a group of biologists called the Upper Mississippi River Conservation Committee (1980). The committee, headquartered in Rock Island, Illinois, is a five-state organization formed in 1943 at Dubuque, Iowa, by the state conservation departments of Minnesota, Wisconsin, Iowa, Illinois, and Missouri. The mission of the committee is

> "...To promote the preservation and wise utilization of the natural and recreational resources of the upper Mississippi River; and
>
> ...To formulate policies, plans and programs for conducting cooperative studies; for the benefit and appreciation of people interested in the natural amenities and values of the River, including fishermen, hunters, boaters, naturalists and others."

That mission has been faced with an ever-expanding commercial navigation project (Rasmussen 1993).

The committee is made up of about 125 biologists representing the conservation agencies of the five states bordering the Upper Mississippi River, and the cooperating federal agencies. I had the privilege of serving as their Coordinator for a 12-year period from 1976 to 1987. The U.S. Fish and Wildlife Service began funding the Coordinator position in 1958, but because the committee's focus has been on fisheries issues and the effects of navigation development, the job has always

been somewhat controversial within the agency. The states, however, have always strongly supported their Coordinator, and that has been a major key to the committee's success.

The Environmental Management Program materialized as the result of a Master Plan (Upper Mississippi River Basin Commission 1982) developed to settle a lawsuit filed against the U.S. Army Corps of Engineers by a coalition of the Izaak Walton League of America, the Sierra Club, and the Western Railroad Association. This lawsuit was filed over the projected effects of the U.S. Army Corps of Engineers' plans to reconstruct Lock and Dam 26 near St. Louis.

A former Upper Mississippi River Conservation Committee Coordinator was instrumental in bringing the proposed reconstruction project to the attention of environmental and railroad interests, and, for that matter, introducing the two. He pointed out that the proposed dam had the potential of quadrupling navigation capacity on the river and in turn significantly affecting the environment and the delicate balance between barge and rail transportation. For that effort, he was attacked by the navigation industry and eventually relocated by the U.S. Fish and Wildlife Service to another part of the country.

The intensity of the political and legal dispute, and the central role that the committee and the Coordinator played in the Lock and Dam 26 issue, was heightened when I was assigned by the U.S. Fish and Wildlife Service to be the Chairman of the Master Plan Environmental Work Team, filling the dual role of representing both the interests of the committee and the Department of the Interior. My job became a real balancing act, and the importance of good interagency and interstate communication, cooperation, and support, especially among the states and the conservation community, was paramount.

The recommendations that follow touch on several factors that I believe were key in organizing and winning authorization and funding of the Environmental Management Program (U.S. Army Corps of Engineers 1990). Some may question the importance I place on various items, but the proof of their importance and successful use is documented by the mere fact that the Environmental Management Program exists. Without the close coordination and dedication of a small group of people (all working for separate states and agencies), I'm convinced that the program could never have won authorization and funding.

Recommendations

1. *Believe in yourself and your mission.* Strong belief in yourself and dedication to your mission are especially important in situations where the odds are stacked against you and where you are trying to bring a large group together for some joint action. Without strong beliefs in the assigned mission, it is difficult, if not impossible, to be an advocate for the resource. And it is imperative that biologists be advocates because if they're not, no one will be. In fact, we must be advocates for our resource to maintain balance and credibility with those who are advocating the development. If we simply take a passive position, critics and colleagues will soon recognize that we are not sincere, our credibility will be lost, and we will be stampeded by the rush to develop.
2. *Motivate yourself and others.* Self motivation and the ability to motivate others is absolutely essential; it comes almost naturally with belief in your mission. Biologists cannot wait around for their superiors or someone else to motivate them because, most likely, that just will not happen. Our superiors may not be motivated themselves. Virtually every member of the small Upper Mississippi River Environmental Work Team was self motivated and enthusiastic. Belief in our mission and self motivation drove us almost like a religious ethic, keeping us going and helping us to overcome every obstacle. And there were many obstacles, including rescoping of our entire effort in mid-stream and cancellation of all of our studies before they were barely started.
3. *Obtain participation from field as well as administrative levels.* The best and most practical information is most often found right at the ground level. Field biologists who live and work on the river every day know it like the backs of their hands. Their input simply cannot be overlooked. One very important factor in our favor on the Upper Mississippi was the committee's network and collective river expertise. I made it a point to get right down to the local district or field biologist for input. In fact, one of the first things I did as Chairman of the Master Plan Environmental Work Team was to make a personal trip down the river, visiting all of the field stations on an information-gathering mission. On one occasion, one of the biologists even followed up my visit with an audio tape of some

ideas he thought of after I left. Because I started from the grassroots and worked up, we quickly gained support, and by the time our work reached higher administrative levels, we had built-in support there, too, because the field biologists had carried our message forward. In fact, the states' central offices were often ready to support our reports nearly on the day they arrived.

4. *Share ownership of the project and its products.* Shared ownership of any project is probably the most important thing to obtain. We did this early on in the Environmental Management Program by contacting the local biologists first. We had colleagues in several states and agencies who shared in authorship and preparation of portions of all group documents. At a bare minimum, the partners always reviewed and concurred with program direction and document contents. Shared ownership not only reduced the Chairman's workload, but also established a sense and pride of ownership, which coauthors, and thus their agencies, defended. As a result, group documents gained credibility with the outside world . The words *cooperation, coexistence, coordination, consensus,* and *collaboration* described all group actions.
5. *Establish and maintain trust among your colleagues.* The business of natural resource management is complex, and most of us not only must have an above average understanding of biology, but also must gain a grasp of chemistry, hydrology, geomorphology, engineering, public relations, advertising, and marketing. So it is not surprising that we often find ourselves working at the very edge of our technical expertise. Because of this, we must be able to develop strong relationships and trusts between one another that cross state and agency lines. We had these strong trusts on our Master Plan Environmental Work Team, and all partners felt confident in pushing the limits of their own capabilities because they knew that others in the group would use their talents and resources to support one another if any mistakes were made. This kind of support and team effort is not uncommon on the Upper Mississippi River. Committee biologists often know one another better and often work more closely with their peers in other states than with biologists in their own agencies.
6. *Don't be afraid to take risks.* Trust among partners encourages risk taking. Hardly anything in our society has ever been accomplished without some level of risk. In fact, risk taking is so important to our economy that we have built-in safeguards in the form of bankruptcy laws to encourage it. One of my frustrations in the conservation field is that most of us are so conservative that we often miss opportunities to change the way the world works. Now, I'm not saying that we ought to go out and risk everything, but as an example, I think we need to try some new habitat management techniques that entail a bit of risk to localized, nonthreatened resources. Such risk taking will advance the state of the art in resource management. We didn't get the Environmental Management Program on the Upper Mississippi without a lot of personal and resource risk. When we were forced to make recommendations on trade-offs between the new lock and dam and the environment, there were those who would have settled for anything for fear that if we asked for too much we would get nothing. The Master Plan Environmental Work Team knew that things would only get worse unless we stood our ground, so we took a risk and recommended an unprecedented \$300 million, 10-year environmental program. We were told that we were nuts! In fact, the U.S. Department of the Interior wanted to settle for only \$19 million. This was during the Reagan–Watt era, when few federal bureaucrats would go out on a limb for the environment. But the fact remains that perseverance and dedication to principles paid off, and we achieved authorization and funding for a \$200 million program. In the process we may have changed the way the world works on the Upper Mississippi into the foreseeable future. Today all biologists on the river, in one way or another, owe their current jobs or a portion of their current job assignments to the Environmental Management Program.
7. *Maintain regular communications through newsletters and other media.* Regular communications are needed between partners, whether it be in a marriage, with our children, or in our professional lives. The more we talk to one another, the more comfortable we become working together, and the better we become at communicating our collective ideas to the outside world. A tool that the committee used for that purpose was its newsletter. During the controversial 1970's and 1980's, the newsletter established the organization, on a monthly basis, as the

"voice of the resource." The newsletter regularly contained controversial issues and criticized governmental policy or position when necessary. During this period, at least two attempts were made by navigation interests to get the Coordinator fired or reassigned, because in addition to being Coordinator he was also the newsletter editor. But these critics underestimated the level of support the Coordinator had with the states and the private sector. In every instance, the states stood behind the newsletter, and it continued to address the issues as the biologists saw them. In fact, the newsletter expressed things that no one state or agency could. And because of the newsletter's broad exposure, the committee became recognized as an unbiased regional advocate for the resource and a credible environmental authority with the general public. Consequently, we were regularly asked to speak about or provide opinions on various riverine resource issues. These opinions were always signed by the Chairman, and the chairmanship rotated annually among the states. Annual rotation of the chairmanship kept opponents off balance because no one person in the UMRCC could be singled out as the target of outside criticism.

8. *Use the grey literature.* I think we are all guilty of holding reams of aging and yellowing data in our files. These data are often the only information available on certain resources, and they need to be published in some form. One way to overcome this problem, in part, is to publish them in the grey literature, such as the Upper Mississippi River Conservation Committee Fisheries Compendium (Rasmussen 1979). This may not meet the strict requirements of refereed journals, but it takes a lot less effort and time. In this form these data at least get exposed to the light of day, and others have the opportunity to evaluate and use them. Your data may be the best available or may represent the state of the art, which those evaluating development projects may have to rely on to either stop a project or mitigate for it. We used grey literature frequently and effectively to justify the Upper Mississippi River Environmental Management Program.
9. *Use expert testimony when necessary.* We used not only grey literature but also, in its absence, expert testimony to justify our recommendations. We were forced into making recommendations for major decisions with no solid data, so we assembled riverine biologists and other technical experts into expert and impact panels, and we went up and down the river pool by pool and reach by reach identifying critical resources, potential effects, and mitigation recommendations. We invited the U.S. Army Corps of Engineers to participate in the exercise, but they chose only to observe. These panels were extremely effective because there was no way the U.S. Army Corps of Engineers biologists or other outside "experts" could argue with the collective opinion of the best expertise on the river.
10. *Build coalitions with constituent groups.* Building support for your projects within the environmental, recreational, fishing, and hunting communities is absolutely essential. We did this by ensuring that the various groups were included on our newsletter mailing list and that literature was hand delivered and oral presentations made at every opportunity. Over a five-state area this may seem overwhelming, but everyone chipped in and did his or her part. So no one person had too large a work load, and the collective impact was large. The tough part was getting the groups to write letters, call their Congressional representative, or take individual action. The groups were generally willing to take action but were generally not technically knowledgeable, so they were uncomfortable trying to put the issues into their own words. We usually had to prompt individual action by providing the various groups with sample letters, clearly showing what needed to be said and done. The down side of this was that some individuals used our sample letters nearly as form letters. It was necessary to stress that their letters be reworded into their own words. Form letters are soon recognized as such, and they are little more effective than a petition. They should be discouraged.
11. *Just do it.* The bottom line to the success of our efforts on the Upper Mississippi River, and probably to any successful program for that matter, is that someone has to "just do it." Don't wait around for someone else to lead the way. Believe in yourself, motivate others, produce the most professional products you can with the resources available, be your own worst critic, do not be afraid to rely on unconventional information sources, take some risks, and go for it! You can make a difference, and in the process you may just change the world.

Conclusion

Just as Kevin Costner's ball field worked to resurrect the old Chicago White Sox in the movie *Field of Dreams*, so did funding of the Environmental Management Program work to awaken a whole array of new river experts and opportunists. During the 7-year legislative process, those of us who believed we could get the program funded were ridiculed by most of the agency bureaucrats. One by one, supporting biologists became discouraged and fell by the wayside. Were it not for the strong dedication and expertise of Dr. David Kennedy of the Wisconsin Department of Natural Resources and now the U.S. Fish and Wildlife Service, I too would have thrown in the towel. Near the end, he and I and Congressman Steve Gunderson (Wisconsin) were the only true believers left. But once the money started to flow, critics of the proposed Environmental Management Program suddenly became experts on the program.

This created problems because while the focus of the effects being addressed in the justifying documents was on fisheries and navigation effects, many program funds were redirected by agency bureaucrats to address other issues. Additionally, original budget estimates failed to plan for the overhead charges assessed by all participants (these ranged from 15 to 38% depending on the participating state or agency). As a result there were not as many funds available for real work as we had anticipated.

Also, fisheries interests, which were in the forefront in the battle to win the Environmental Management Program, have frequently taken a back seat to waterfowl interests and overhead charges in program implementation. The lesson here is that when funds start to flow, memories of how funding was justified are short, ethics seem to be of little importance, and hard fought funding can get spent on all kinds of seemingly unrelated activities and administrative expenditures. It may not be possible, but future bills would do well to have some form of built-in requirement that ensures that limits are placed on overhead charges and that funding is appropriated only to produce the products justified by original needs. But even though implementation of the Upper Mississippi River Environmental Management Program has had its problems, most biologists working on the Upper Mississippi River today would agree that it is a successful program, and one that they would fight to keep.

The bottom line, however, is that the Environmental Management Program could not have been achieved without the efforts of a small group of people who had not only a vision but also the determination and dedication to make that vision come true. Others on other rivers can do the same if they establish strong mechanisms for communication, cooperation, coordination, and comradery. But more than anything else, someone, some group, or some state or agency has to come forward and assume the leadership responsibilities and risks, and not be afraid to "just go for it."

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Restoration Planning for the Rivers of the Mississippi River Ecosystem: Summary

by

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Abstract. Historical trends in river habitat and fisheries quality were reviewed for 20 river systems at the symposium on Restoration Planning for the Rivers of the Mississippi River Ecosystem held at Rapid City, South Dakota (14–17 September 1992). A great variety of uses compete with recreation (all 20 rivers), commercial fishing (9 rivers), and shelling (3 rivers). Major uses and changes influencing aquatic biota include impoundment, channel modifications, irrigation, barge traffic, loss of riparian floodplain and instream flow, introduced fishes, and a host of water quality problems. Despite the many problems listed, management successes were evident in improved water quality (8 rivers), movements to adopt holistic management plans (6 rivers), unchanged or improved fisheries (12 rivers), and changing public attitudes toward river values. Information on riverine biota was included for plankton (7 rivers) and macroinvertebrates (15 rivers). Declining mussel fauna was a concern on several rivers. Data on fish ecology included biomass estimates (6 rivers), mesohabitat associations (13 rivers), zonation (7 rivers), flow relations (5 rivers), species richness over time (9 rivers), fish migration (6 rivers), and riverine productivity and food webs (20 rivers). Speakers listed needed river restoration methods, chiefly riparian habitat management, flow manipulation, improved soil conservation, and implementation of basinwide management plans. Biomonitoring data was the most mentioned information need, although several innovative biomonitoring and management plans are in use. Forestry management for fish was the most mentioned of nine research needs.

The symposium, "Restoration Planning for the Rivers of the Mississippi River Ecosystem," held at the Annual Meeting of the American Fisheries Society in Rapid City, South Dakota (14–17 September 1992), can be added to the list of rivers symposia and books that have increased in frequency since Hynes' treatise "The Ecology of Running Waters" (Hynes 1970; Oglesby et al. 1972; Krumholz 1980; Welcomme 1985; Smart et al. 1986; Matthews and Heins 1987; Benson 1988; Hunt 1988; Dodge 1989; Gore and Petts 1989; Calow and Petts 1992). The symposium comprised 34 reports on the status of 20 individual rivers (Table 1) that compose about one-third of the 3.2-million-km^2 Mississippi River basin (Figure).

Reports covered rivers from the easternmost drainage (Pigeon) to the westernmost drainage (Yellowstone) and from the northern prairies (James) to the southern swamps (Big Black, Yazoo). Two rivers (Yellowstone, St. Croix) have had few anthropogenic perturbations and might be considered reference rivers. The St. Croix and a 91-km-long portion of the middle Missouri River are the only rivers included in the symposium that are designated as Wild and Scenic Rivers. The White River may be the most altered. We summarize major points about the status of the rivers and their fisheries, and list speakers' recommendations for river management and restoration.

Competitive Uses of Rivers

Competitive uses of rivers are well known and succinctly summarized by Saylor et al. for the smallest river represented at the symposium—the Pigeon River (North Carolina and Tennessee). They listed six uses: industrial, domestic, hydropower, agriculture, recreation, and maintenance of aquatic life. When we compared these with the uses of the largest river discussed at the symposium (Missouri), we found them nearly identical, except that navigation is also important on the Missouri. One or more of these uses is made of each river reported at the symposium.

Most reports on rivers in the lower Mississippi River basin echo a similar theme—restoring riverine natural resources depends on restoring the

Table 1. Selected physical and biological attributes of 20 rivers covered in the symposium.

	Physical				Biological		
River (state)	River at terminus	Watershed drainage area (km^2)	Length (km)	Mean annual flow[c] (cms)	Fish[a]	Mussels[b] and macroinvertebrates	Algae
Arkansas (CO, KS, OK, AK)	Mississippi	414,368	2,333	1196	F,R,C	M	
Big Black (MS)	Mississippi	8,770	434	108	F,R	M,I	
Big Muddy (IL)	Mississippi	6,182	248	50	F,R,C		
Embarras (IL)	Wabash	6,250	310	34	F,R	M,I	
Illinois (IL)	Mississippi	75,136	526	627	F,C		
James (SD, ND)	Missouri	57,000	760	11	F,R	M,I	X
Kankakee (IL, IN)	DesPlaines	13,277	241	127	F,R,C	M,I	
Kansas (NE, KS, CO)	Missouri	159,177	772	199	F,R	M,I	X
Kaskaskia (IL)	Mississippi	11,378	523	104	F,R	M,I	X
Little Wabash (IL)	Wabash	8,298	382	74	F,R		
Minnesota (MN)	Mississippi	44,300	597	106	F,C	I	X
Missouri	Mississippi	1,354,570	3,768	2174	F,R,C	M,I	
Pigeon (TN, NC)	French Broad	1,784	111	19	F		X
Powder (WY, MT)	Yellowstone	34,300	800	16	F,R	I	
St. Croix (WI, MN)	Mississippi	20,018	276	122	F,R	M,I	
Vermillion (SD)	Missouri	5,781	220	8	F,R	M,I	X
Wabash (IN, IL)	Ohio	85,500	764	789	F,C	M	X
White (MS, AK)	Mississippi	71,911	1,159	751	F,R,C	M	
Yazoo (MS)	Mississippi	34,700	271		F,C		
Yellowstone (MT)	Missouri	182,336	1,091	362	F,R	M,I	

[a] C = commercial fishing, F = recreational fishery, and R = rare species.

[b] M = mussel data, and I = other macroinvertebrates.

[c] Data from USGS station closest to the terminus.

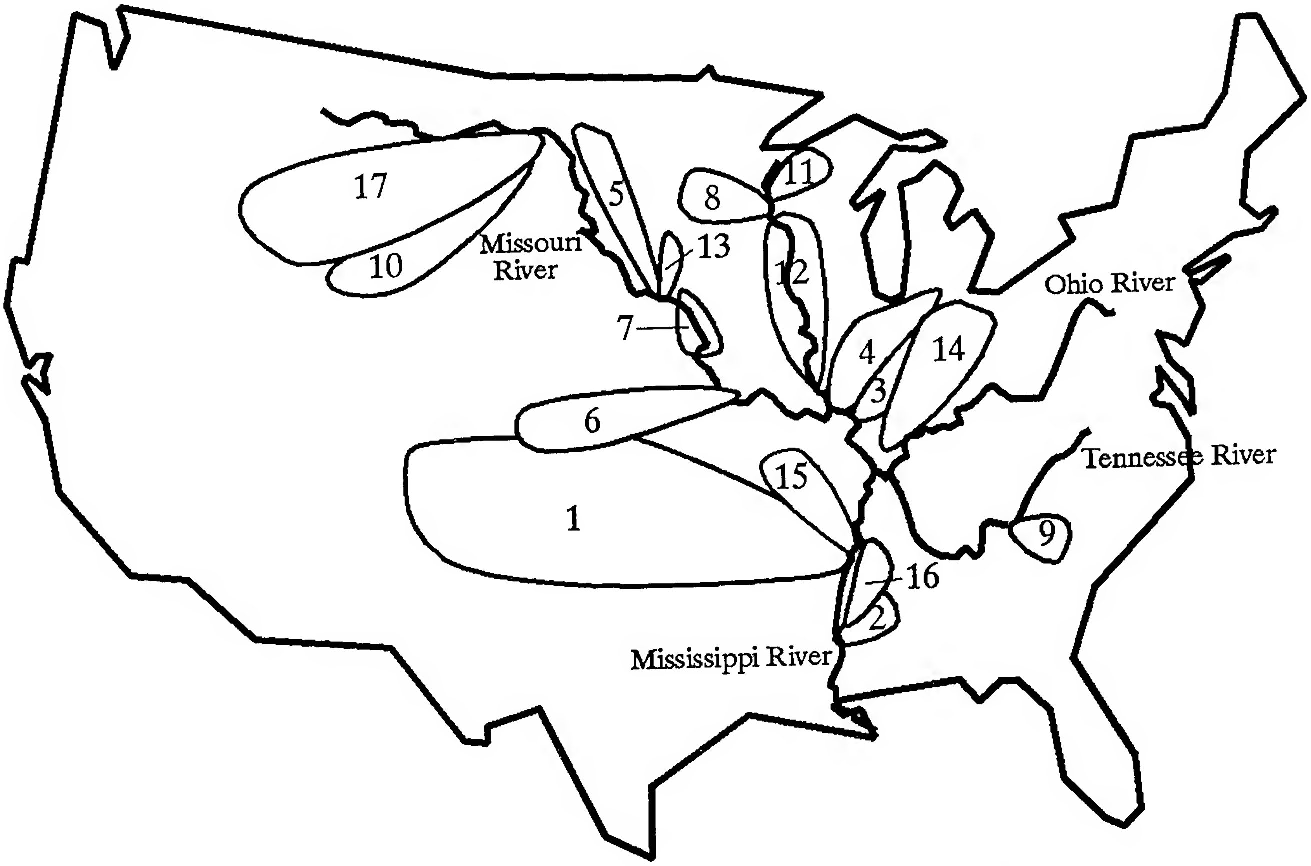

Figure. Map showing approximate basins of rivers included in the symposium: 1. Arkansas River, 2. Big Black River, 3. Big Muddy and Kaskaskia rivers, 4. Illinois and Kankakee rivers, 5. James River, 6. Kansas River, 7. Middle Missouri, 8. Minnesota River, 9. Pigeon River, 10. Powder River, 11. St. Croix River, 12. Upper Mississippi River, 13. Vermillion River, 14. Wabash and Embarras rivers, 15. White River, 16. Yazoo River, 17. Yellowstone River.

river–floodplain connection and a more natural hydrograph. However, integrating natural resource benefits into the totality of river-basin uses is a complex process (Cieslik et al.), particularly when endangered species are present (Keenlyne). Kallemeyn et al. present a case history of addressing conflicting needs of water users and restoration of the natural hydrologic regime in the Rainy Lake–Namakan Reservoir ecosystem.

The seven papers on the Missouri River represent, on a grand scale, the problems and problem resolutions outlined on a smaller scale for individual rivers. Flow regulation, particularly lowered peak flows, has reduced cottonwood–willow riparian forest regeneration on the Missouri, and Johnson suggested corrective measures. Evidence reported by Mestl and Hesse relates drastically lowered production of aquatic insects to disappearance of backwater habitats. Latka et al. compared historic and contemporary flow patterns to illustrate how information on hydrology and channel geometry aid resource managers in selecting sites for restoration. Simulation techniques for modeling mobile bed materials, presented by Holly and Ettema, may be useful tools for river restoration planning. A review of the Boyer Chute, Nebraska, restoration project by Harberg et al. shows us that teamwork between biologists and engineers and postproject monitoring are critical elements to successfully implementing floodplain habitat restoration. Planners of basin-wide restoration projects on the Missouri and other systems will be helped by experiences of those working with the upper Mississippi River (Rasmussen

et al.). The time may be right to implement an ecosystem approach to planning on the Missouri River (sensu National Research Council 1992), as has been undertaken for other large interjurisdictional rivers such as the Columbia (Graham 1988) and upper Mississippi (Rasmussen et al.).

Physical Features

Most authors presented information on physical features of the river basin, particularly hydrology, geology, climate, land use, and impoundments. Basin scale ranged from the 1,784-km^2 basin of the Pigeon River to the 1.35-million-km^2 basin of the Missouri (Table 1). Most of the rivers reported on are principal tributaries of either the Mississippi (10) or the Missouri (4) rivers.

Primary Production

Few authors were able to supply information on primary production, the most complete reports being for the Kaskaskia, Minnesota, and Kansas rivers. Aquatic macrophytes were seemingly not abundant enough to be considered important to riverine ecology by most authors, with the notable exception of the Illinois, where Sparks discussed the importance of aquatic plants to recovery of that system.

Periphyton production was high in certain rivers (e.g., Kaskaskia, 1,650 mg/m^2), but low in others (e.g., Minnesota) because of lack of suitable substrates. Kavanaugh (Minnesota River) reported on the use of in situ peryphiton bioassays to monitor riverine water quality. Mestl and Hesse found a decline in periphyton production over a 17-year period in the backwaters of the Missouri River.

Seven authors reported on riverine phytoplankton (Table 1), but few had data on zooplankton (Kansas, Kaskaskia). In general, diatoms dominated the riverine phytoplankton (Minnesota, Kaskaskia, Wabash, Kansas), except in sluggish rivers (James) or where eutrophication was a factor (Pigeon, Wabash), and then respiration from bluegreen algae could represent 50–70% of the dissolved oxygen demand (Wabash). Increased flows decreased plankton density (Wabash, Kansas). Water releases from dams may (Kaskaskia) or may not (Kansas) contribute to the riverine plankton community.

Macroinvertebrates

Eleven papers had information on distribution and abundance of macroinvertebrates and 13 on mussels (Table 1). The high number of reports that included data on shellfish was surprising and may signal increased work with this group. Mussel communities are in general decline, and authors reported presumed extirpations of 1 to as many as 14 taxa (Table 2). Commercial shelling takes place in the Wabash, White, and Arkansas rivers.

Dipterans dominated most macroinvertebrate communities (Yellowstone, Missouri, Minnesota, James, Vermillion, Kansas); oligochaetes dominated benthic fauna of the Kankakee. The St. Croix supported 497 taxa, compared with the 10–19 species in the Yellowstone.

Macroinvertebrates were used for biomonitoring in the Embarras, Kankakee, Kaskaskia, and Minnesota rivers. Species richness and numbers declined downstream (Yellowstone, St. Croix) and at stations influenced by pollution. An endangered elmid beetle was listed in the Kansas River.

Only three authors had data on macroinvertebrate (excluding mussels) trends with time (Missouri, Kankakee, Kaskaskia). The longest comparison was over a 17-year period in the middle Missouri River, where production declined 64% from 1963 to 1980 (1.14 to 0.49 g/m^2; Mestl and Hesse). There were daily drift cycles and seasonal cycles in the Kaskaskia macroinvertebrate communities.

Most authors made observations about habitat associations, particularly differences between communities in tributaries and main rivers. In general, communities in tributaries were more variable (Minnesota, Embarras, Kankakee) and had more taxa or production (Embarras, Powder) than did those in main rivers. Detailed studies in three rivers (Missouri, James, Kansas) concerned community associations with substrate (e.g., snags, rocks, sand, silt). Macroinvertebrate production from snag habitat declined 71% between 1963 and 1980, may have promoted a shift from insectivorous to zooplanktivorous cyprinids (Mestl and Hesse), and decreased food availability to shovelnose sturgeon (Latka et al.).

Fish Abundance

Data on fish ecology included biomass estimates (6 rivers), mesohabitat associations (13 rivers), zonation (7 rivers), flow relations (5 rivers), species richness over time (9 rivers), and fish migration (6 rivers). Commercial fish harvests have generally declined through time, but commercial fishing still takes place in nine rivers (Table 1). Recreational fishing occurs in all rivers and is reported to be exceptional in the Big Black, St. Croix, Arkansas, and Kaskaskia rivers.

Fish species richness varies widely among rivers or river basins, ranging from 28 taxa for the Powder to 163 in the White River basin (Table 2). Nearly all authors reported numerous introduced fishes, with 15 or more species present in the Arkansas, White, and Yellowstone rivers. However, the impact of nonnative fishes is far greater in the Yellowstone, where they compose 36% of the number of species compared with 13–16% for the speciose Arkansas and White rivers (Table 2).

Biomass data are difficult to obtain for river fisheries, but six authors reported biomass values ranging from 9 to 1,390 kg/ha (Table 3). Most values were in the 200–700 range, which agrees with a summary presented by Hynes (1970) for the world's rivers. Lower reaches of rivers supported higher fish biomass.

Fish community data for most rivers have been collected recently because of impact assessment needs. Early faunal surveys on seven rivers allow analysis of historical trends, although it is difficult to account for bias because of the use of different collection methods and effort. Data from the Big Muddy indicates that species richness often depends on sampling effort.

Most historical data are available from rivers in Illinois (Kaskaskia, Embarras, Little Wabash, Wabash, Illinois) because of the early 1900's work by S. Forbes of the Illinois Natural History Survey. The number of species present in Illinois rivers has remained relatively unchanged for 80 years. Explanations for this apparent stability abound. Many temperate stream fish are adapted for living in an environment that fluctuates, and most are ecological generalists. Alternatively, major anthropogenic changes in faunal composition may have already taken place by the early 1900's. The same trends in species richness over time

Table 2. Fishes and mussels reported from 20 rivers in the Mississippi River basin. Reports include introduced fishes, fishes and mussels state or federally listed, and the number of species presumed extirpated. Blanks indicate no reports by author, not necessarily absence.

	Number of species of fishes					Number of species of mussels			
River	Main-stem	Basin	Introduced	Listed	Presumed extirpated	Main-stem	Basin	Listed	Presumed extirpated
Arkansas	126		20	17	7				
Big Black	112		2	3		31		1	
Big Muddy		106	9		10				
Embarass		101	7	4	5	32		10	7
Illinois									
James	57		7	7		4			13
Kankakee		99	7	7	2		35	12	4
Kansas	73	99	11	16		4	11		2
Kaskaskia		125	13	6	3	42		11	14
Little Wabash		74		1					
Minnesota		92	4						
Missouri and tributaries	81		7	6					
Pigeon	75		3						
Powder	28		5	2					
St. Croix	83	110	6	9	7		40	12	
Vermillion	41		8	1			9		5
Wabash	94					75		3	14
White	126	163	17	1	1		58	5	1
Yazoo		37							
Yellowstone	56		20	4					

Table 3. Biomass of fish in selected rivers of the Mississippi River basin.

River	Biomass (kg/ha)	Comments
Kansas		
Tributaries in Kansas	168–496	Average, range = 2–893 kg/ha
Tributaries in Nebraska	61–90	Two stations with high common carp numbers excluded
Lower mainstem	383	Five sites, range = 160–845 kg/ha
James	667–1,190	All fish depending on habitat
Yellowstone		
Upper river	9–39	Trout only
Lower river	1,390	All fish
White		
Mainstem, lower	738	50% blue catfish
Tributaries	88/276	Channelized/unchannelized
Oxbows	351/600	Cleared/forested
Arkansas		
Kansas portion	102–303	
Navigable pools	375–1,065	
Kaskaskia		
Mainstem, upper	45–808	Uncorrected 1960s rotenone sample, 21% game fish
Tributaries, upper	32–191	Uncorrected 1960s rotenone sample increased in 1980s samples
Tributaries, lower	1–432	Uncorrected 1960s rotenone sample

were apparent in the Vermillion, James, Kankakee, Big Muddy, and upper Mississippi rivers—about equal numbers of species increased or decreased in frequency of occurrence in collections. For example, in eight stations on the Vermillion River, eight species of lithophilic fish increased in collection frequency over 35 years and seven decreased.

Stability in species richness does not imply that abundance, distribution, and community composition have been stable. Some authors mentioned that fish assemblages (particularly cyprinids) had changed from those preferring low turbidity and hard bottoms to those tolerant of disturbed habitats (James, Big Muddy), or that ranges had been reduced for some species (James, Embarras). Methods for assessing river health through analysis of fish community structure, such as the Index of Biotic Integrity, have been in use long enough to allow comparisons over a 13-year period in the Little Wabash River; there were no important changes in the index. In contrast, analysis of catch-per-unit-effort data from the 1950's in the middle Missouri River show that five species of *Hybopsis* chubs, two species of minnows, burbot, sauger, and blue catfish have declined in abundance. Most rivers had fish listed as endangered, threatened, or of special concern, and presumed extirpations were noted for seven rivers (Table 2), although in some instances particular species were never abundant.

Fish Distribution

Running waters display longitudinal and horizontal biotic zonation, and fisheries data presented by several authors support this general idea. Data from the Yellowstone are most applicable, with the transition from a coldwater, low diversity fishery in the mountains to a warmwater, high diversity fishery at its terminus. Most rivers were more speciose in their lower than upper mainstem reaches (St. Croix, Black, James, Arkansas, Little Wabash) because of habitat changes or immigration of fish from the receiving stream (St. Croix, James, Kaskaskia, Big Muddy).

Fish communities tended to vary among tributaries, depending on land use. In some instances, poor water quality lowered fish diversity (St. Croix, Big Muddy), but in others, tributary populations were higher than in the mainstem (Kaskaskia, Embarras, Powder), or were different

because tributaries served as refuges for species preferring clearer water (James, Kansas).

Fish-habitat relations have long been an area of research, primarily because many river development projects include removal or alteration of instream habitat. Certain species (e.g., channel catfish, James) or guilds (Kansas) are usually more abundant near complex instream habitat than in areas that lack instream structures (e.g., snags, rocky substrates, pools). Data supporting this generalization were presented for the Little Wabash (shallow water only), Black (flathead catfish and snags), James (biomass), Kansas (guilds), and Kankakee (density, diversity, biomass). Channelized portions of the White River held 24 species, whereas natural river reaches held 45 species. Navigation pools enabled 46 new species to colonize the Arkansas River.

Flow characteristics are important in habitat specialization (Gorman and Karr 1978) and fish migration. Decreased flow variability can increase species richness (Little Wabash). High flows allow more upstream migration (Powder, Yellowstone) than low flows. Drought the preceding year can help (Wabash, Kankakee) or hurt (James, Yazoo) fish populations.

Data from a group of rivers represented by the Illinois, Kankakee, Kaskaskia, middle Missouri, upper Mississippi, White, and Kansas rivers highlight the importance of the floodplain and floodplain pools to river ecology. Larimore's discussion of the Kaskaskia is the most thorough treatment of this subject. Distinct fish assemblages occur in river channel and pool environments (Kaskaskia, Wabash, Kankakee). When floodplain-exploitative species are forced off the plain, they seek backwater habitat. In the Kankakee, 25 species were lost when floodplain habitat declined.

Fish Migration

There were several instances of fish species stocked in impoundments later becoming part of the riverine fish community for as much as 100 km of river (Kaskaskia, Little Wabash, Powder). Sedentary (smallmouth bass, rock bass) and mobile (several) species were identified in the Kankakee. Seasonal migrations upstream in spring and downstream (sometimes to reservoirs) in autumn were documented in the Yellowstone (walleye) and Powder (channel catfish, shovelnose sturgeon). Trout species in the Yellowstone exhibited homing behavior.

Of course, dams were cited as impediments to fish migration in several rivers (James, Missouri, Big Muddy, Embarras, Powder). However, lowhead dams and locks were usually navigable by most fish (James, Kankakee), but they were impediments to paddlefish and sturgeon on the Yellowstone.

River Restoration

All authors reported some degree of river modification, and the list of conservation needs is extensive (Table 4). Nevertheless, there is some good news about the condition of many rivers. A few need little or no restoration (Black, Vermillion, Powder, St. Croix, Yellowstone). Water quality has improved on nine rivers, although consumption advisories or other contaminant problems were reported in seven rivers. Fisheries have improved over the last 20 years on the Illinois, Black, Wabash, and Yazoo rivers. These successes confirm our beliefs that the time and expense devoted to restoration will yield visible benefits to the resource. Much still remains to be accomplished, and many creative approaches are underway.

A new appreciation for America's rivers is indicated by projects such as those on the upper Mississippi where $200 million is authorized for restoration; Missouri and Pigeon, where natural resource values are beginning to be used to allocate resources; and Kansas, Pigeon, and Arkansas rivers, where improved regulations are in effect for flows, dredging, and pollution.

Innovative habitat management experiments are underway on the Big Muddy and Pigeon (contaminant management by capping), Illinois (macrophyte management), Missouri (chute restoration, productivity boosting), Yellowstone (low flow augmentation, leasing water rights), and White rivers (levee modification, fish refuges). Several kinds of models and biomonitoring tools are being used to improve river fisheries management (Table 4).

Holistic management and a river "ethic" are prevalent in authors' discussions of some rivers (upper Mississippi, Missouri, Illinois, Minnesota, St. Croix). But for most rivers, management actions shift with political boundaries and economic realities, prompting symposium speakers to list

Table 4. Summary of recommendations for river conservation and needed research for rivers described in the symposium..

Major Restoration Needs

- Protect riparian habitat from development, especially forested floodplain and wetlands, reclaim forests (6 rivers)
- Determine and protect minimum flows; provide additional flows (7 rivers)
- Conserve rivers with holistic, basinwide management plans (6 rivers)
- Use best management practices for soil conservation including vegetated buffer strips along stream corridors (10 rivers)
- Restrict channelization, clearing, and dredge spoil disposal to protect existing uses (5 rivers)
- Other suggested restoration:
  - Reclaim areas impacted by mine wastes
  - Stabilize banks and restore the river channel
  - Modify dams and dikes to improve fish passage
  - Reconnect river to erosion zone
  - Pursue water rights and riparian land acquisition
  - Include recreation when reauthorizing multipurpose projects
  - Identify ecologically significant uplands and aquatic areas
  - Develop reservoir releases that benefit fisheries
  - Penalize violators commensurate with the degree of loss
  - Enforce NPDES and other permitting requirements
  - Discontinue stocking nonnative fish until impacts are assessed
  - Control harvest of remaining stocks of declining species
  - Curtail wetland drainage until holistic plans are made
  - Improve stream access sites, particularly boat ramps
  - Increase public awareness about river ecology and values

Monitoring and Research

- Reliable biological data (biomonitoring) to assess stream and tributary integrity and status of rare fish (6 rivers)
- Forestry management for fish (i.e., revegetation, habitat rehabilitation, techniques, thresholds [5 rivers])
- Other research needs:
  - Combine fish and wildlife management
  - Riverine fish migration ecology
  - Life histories of nongame fishes
  - Long-term studies of population fluctuations
  - Behavior of residual Dioxin
  - Classify rivers by sensitivity of riparian zone to flow regulation
  - Investigate restoration of river productivity
  - Develop sediment bypass methods

basinwide management planning as one of the top four needs (Table 4).

Several trends emerged when management recommendations for each river were collated (Table 4). Three of the four most stated needs did not concern the river proper, but instead concerned conservation efforts in the uplands and riparian corridor and basinwide planning. Providing flows for fish was the fourth most stated need. Other recommendations were more site specific, and indirectly point to the wide variety of perturbations in America's rivers (Benke 1990).

Most authors did not mention research or information needs, perhaps indicating that methods for restoring rivers are generally known and simply need application. The most stated research need concerned how to best manage riparian forests and to protect river quality. Several authors wanted more biomonitoring information.

Conclusion

Many fishery management controversies in North America today involve our great estuaries (e.g., Chesapeake Bay), our Great Lakes, our great rivers (e.g., Potomac, Mississippi, Missouri, Columbia, Ohio, Colorado), and a diffuse but also

great resource, our wetlands. Controversies over these waters usually arise because several groups have economic interests in the resources and because these resources are limited or degraded, requiring allocation policies.

Traditional approaches to allocation of natural resources have usually favored industrial uses, but recreational and esthetic values of fish and wildlife and their habitats have recently been given increased attention. Holistic approaches and recognition of the intrinsic value of nature are beginning to influence policy makers. We anticipate a more biocentric approach (Higgs 1987; National Research Council 1992) to river conservation, which has usually come about by public mandate through legislation. If this prediction is accurate, recreation could become more important in the future than some other industries that use the rivers. This would challenge fish and wildlife biologists, whose recommendations might have as much weight in future planning as those of barge operators (for example) in the past.

Quotations from several symposium speakers can be used to summarize the history and biota of the rivers of the Mississippi basin and depict the biologists who study them. Resignation to decades of despoliation is indicated in Durham's comment on the Embarras...

> In the 43 years or so of this writer's observations of the river, it has become an expected occurrence that when a heavy rain falls in Champaign or Douglas county, the rich black soil from those areas will soon be passing by Coles County in the dark, muddy appearing water.

Resiliency of the riverine fishery which was reported by many speakers is capsulized in the statement by Burr and Warren (Big Muddy) that ...

> ...performance of the bulk of the fauna is a testament to the ability of fish communities to respond and persist under a variety of stochastic processes.

An unstated mood at the symposium is summarized in statements by Jackson et al. (Upper Yazoo) about rivers...

> There is magic in moving water. Swirling currents have captivating powers over persons seeking and sensitive to the rhythms of the earth. We are drawn to rivers not simply for the tangible resources they afford but because they communicate to us the power of eternal forces relentlessly at work.

and river biologists...

> As river resources professionals, we stand firm on the foundation that floodplain rivers and their fisheries are integral, valuable components of our societies, and that their loss is to the detriment of the quality of life our Nation's citizens should enjoy.

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Epilogue

by

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The Mississippi River basin is bounded by the Appalachian Uplands, including the Allegheny and Blue Ridge mountain ranges on the east, and by the Rocky Mountains on the west. The catchment is exceeded in size only by the Amazon, Congo, and Nile River watersheds. The Mississippi River system played an important role in the settlement of North America. The abundant finfish and shellfish were essential in the diet of basin colonists, and important to their economy as well. Commercial fisheries developed in the 1800's throughout the basin. The rivers were large and the fisheries viewed as limitless, and because many river fishes are migratory, often moving in and out of different states, data acquisition and management were nearly nonexistent (Rasmussen 1991).

Leopold (1949) remarked "like winds and sunsets, wild things were taken for granted until progress began to do away with them." Such is the case with the wild resources of the rivers in the Mississippi River basin. Most of the large river systems in the basin have been dramatically altered by dam building, channelization, levee construction, pollution, and changing land management practices. Today, sustainable yield of various resources is only a fraction of historical production. We now realize that rivers have intrinsic value, independent of the human benefits that can be derived from them, and that there are explicit and implicit social and economic values associated with rivers that can be affected by human interaction with these systems (Malvestuto 1989). If we are to effectively restore and protect lost wild values in these river systems, we must focus on a set of beliefs to guide our actions. Larkin (*The wet revolution: fisheries production to the year 2025; 1991, unpublished speech*) provided good principles to follow: (1) The principle of long term sustainable yield—stocks of fish should not be harvested to levels that endanger recruitment; (2) The principle of social and economic development—the resource should serve the greatest common good; (3) The principle of democratic values—all users should have an opportunity to present their views; and (4) The principle of protection of the environment for fish—without which there is no resource to manage.

The scientists that presented papers at this symposium have addressed these principles to some degree. However, we cannot achieve real restoration until we learn to incorporate the views of other competing interests. To that end, the following individuals with special expertise and insight provided oral comments in a wrap-up presentation at Rapid City. I have excerpted a few of their comments here. They also fielded questions for more than an hour after the conference was concluded. I thank them for their important contributions.

Colonel Gaylerd E. Davis, is the Deputy Military Commander in the Missouri River Division, and he represented the Chief of Engineers (General Arthur E. Williams). He noted the role of the U.S. Army Corps of Engineers in the business of nation building during the last century. By necessity that role included flood control, water supply, hydropower, navigation, and irrigation. This construction clearly created some of the environmental problems that must be dealt with today. The Corps has responded to the environmental awakening of the 1970's by becoming more sensitive to the needs of the environment. As a start, the Corps has hired a professional staff of environmental experts to provide technical input into its decision-making process. New Corps programs must now be judged by the three E's—engineering, economics, and environment. He also pointed out that new developments must try to avoid environmental effects first, failing that, minimize effects, and lastly, mitigate effects. As a public service organization, the Corps takes direction from the

President and Congress. Recently, there has been a congressional mandate for environmental protection. New legislation has exemplified the need to find local cost-share partners that have a greater involvement in the design and construction of projects, and environmental mitigation must now take place either before or during construction. In some cases mitigation may even be retroactive to Corps projects from the recent past. The 1993 budget includes $812 million for environmental programs, a level of funding that will allow the Corps to do many good things. The Corps has over 1,400 projects nationwide that can be remediated for positive environmental benefits. Colonel Davis recognized the challenges ahead, specifically, public education and coalition building. He pointed to the immense amount of data available for this conference, and he suggested that the present need is to put all of these pieces together to achieve results.

J. M. Jess is the Director of the Department of Water Resources in Nebraska. He brought a real insight into the conflicting demands for water along a large river system because he has been responsible for moderating the issue of Platte River water usage in Nebraska. The Department of Water Resources was created to oversee the implementation of water law in this semiarid and highly agricultural state. The decisions made by the director can be appealed only to the Nebraska Supreme Court. In this forum the rules of evidence apply, and in the cold light of a supreme court review, emotional rhetoric somehow seems out of place. Decisions on whether to provide water for fish and wildlife versus agricultural or domestic use must rest on credible data. Most biologists possess good data but have rarely been required to present it under direct cross examination. However, when biologists are finally prepared to argue their case in such a forum, understanding and resolve is strengthened. Moreover, this process provides a good opportunity to develop coherent reasoning for the protection and enhancement of fish and wildlife that can be understood by nonscientists living in the basin.

Colonel James E. Corbin is retired from the position of District Engineer in the St. Louis, Missouri, district of the U.S. Army Corps of Engineers. At present he is a Design Engineer for Johnson Controls World Service, Inc. He pointed out that if we cannot manage the Mississippi River ecosystem intelligently, we are not going to be a role model for other major river ecosystems facing a similar fate in the developing parts of the world. He believes that if we give people a meaningful framework to operate within, and a little technical guidance, they will do great things on behalf of themselves and their environment. It is important to put that framework in place and to turn people loose to succeed. He pointed out that our ecological infrastructure has enabled us to create an economic infrastructure, by using our natural resources of water, soil, plants, and animals. The natural world works with humans as an integral part; we should not be apart from the natural world. Yet our present society has created an intellectual void in terms of understanding our rivers and how we interact with them. Colonel Corbin emphasized the importance of environmental education, and he recommended an action agenda. You will never have the perfect answer, he noted. When you are close its time to say good enough and move toward implementation. Leaders must make the hard decisions, even though they may cause personal or professional problems. He believes that people of integrity and honor must try, and that failure to try may be one of the reasons that government often fails. Too often, decision makers abdicate their responsibility to a "grey shapeless bureaucracy to avoid accountability." He suggested that if we make timely, rational decisions, we will begin to trust each other, and issues will be resolved simply because of that trust. Work toward success by using successes. Find what you can agree on and go do it.

J. Martin, as Chief of Fisheries for Oregon Fish and Wildlife, has been involved in a major restoration effort on the Columbia River for the past several years. He pointed out that no matter what system is the target for restoration, professionals must go through two stages before results are achieved. The first stage is denial—"Oh, there's no problem, it's always been like this." The second stage is fingerpointing and blame. Only after successfully negotiating through these stages can we achieve serious strategic understanding, review tactics, create action plans, and start to do what the public expects professionals to do. These two stages do not help to achieve a synthesis between scientists and politicians to create action. Anything short of creating that synthesis is a waste of time. The Mississippi River basin is much larger than the Columbia River basin. Its more institutionalized, and as a result there is more work to be done. Mr. Martin believes that we cannot create a restoration program without a linkage to the inner values of the people of the basin. It is important to define and

display the living heritage that is important in the Mississippi River basin. Congress created the Northwest Power Planning Council as a consortium of state and federal governments. A structure for organizing and coordinating the scientists and decision makers is essential in the Mississippi River basin as well. He also suggests we move away from the status quo. Most important, we need an informed public and informed advocates, and they must generate an awareness of the stakes involved in not generating real restoration. He says to be constructively dissatisfied, create energy by being patient and persistent, and put technical leaders out front so good answers are given to good questions.

In my view, the scientists and panel members have provided an agenda for restoration of this basin.

1. Educate the citizens of this basin about the intrinsic values of large river ecosystems and how such ecosystems must be allowed to function if they are to be restored and preserved.
2. Create advocacy groups to generate localized pride in river restoration projects.
3. Expand MICRA to perform the role of basin coordinator for river restoration by enhancing the role that nongovernment people play. MICRA must truly aspire to the concept of wise use for the greatest common good.
4. Assist with the creation of "reference reaches," as defined by the National Research Council (1992), to recreate natural river–floodplain interactions on 50 large river segments that can serve as restoration templates.
5. Manage harvest in a manner consistent with the concept of optimum yield.
6. Integrate, more completely, the contributions of river scientists into the decision-making process, and establish real time-frames for implementation.
7. Establish a protocol for setting and reaching bench marks to determine success or failure of implemented programs; eliminate ideas that fail, and expand on ideas that work successfully.

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TAKE PRIDE

in America

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL BIOLOGICAL SURVEY

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